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Instream flow studies on the Little Greys River

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Abstract

One segment was selected for instream flow water rights filing consideration on the Little Greys River, a tributary of the Greys River near Alpine, WY. The segment was selected considering land ownership, hydrology, and stream channel characteristics to maintain or improve the Snake River cutthroat trout (SRC) fishery in this stream. The species is common throughout the Greys River watershed, which is managed as a wild SRC fishery. This report provides flow recommendations for the Little Greys River developed from studies conducted in 2010. The modeling technique employed to develop instream flow recommendations for maintaining SRC spawning habitat during spring runoff was fisheries habitat evaluation with the River 2D model. Riffle hydraulic characteristics were examined using the Habitat Retention approach to ensure that flow recommendations from other methods did not impede fish movement. The Habitat Quality Index (HQI) model was used to assess the relationship between stream flow and juvenile and adult trout habitat quality in the summer. During the winter months, November through March, natural winter flows were recommended to maintain all life stages. The 20% monthly exceedance was selected to represent natural winter flow. Finally, a dynamic hydrograph model was used to quantify flow needs for maintenance of channel geomorphology.

Approximately 4.5 miles of stream habitat will be directly protected if this instream flow application advances to permit status. Recommended flows range from a low of 28 cubic feet per second (cfs) during the winter to 60 cfs during summer.

Introduction

There are five primary riverine components that characterize a stream or river: its hydrology, biology, geomorphology, water quality and connectivity (Annear et al. 2004). When the hydrology is changed, other components are influenced to varying degrees. As water resources are developed in Wyoming for out-of-stream, or consumptive, uses there are corresponding changes in other riverine components that may alter the quality of a stream for supporting fisheries habitat. Rivers and streams are important to the residents of Wyoming, as evidenced by the passage of W.S. 41-3-1001-1014 in 1986 that established instream flows as a beneficial use of water when used to maintain or improve existing fisheries. The statute directed that any unappropriated water flowing in any stream or drainage in Wyoming may be appropriated for instream flows when it provides this beneficial use (see Appendix A for more information on instream flows in Wyoming). The statute and Wyoming water law clearly note that all existing water rights in that stream remain unaffected by a permitted instream flow water right.

Purpose for Greys River Instream Flow Studies and Water Rights

The Wyoming Game and Fish Commission initiates all studies designed to evaluate the instream flow needs for fisheries in Wyoming. These studies do not address all five riverine ecosystem components or all aspects of each component (e.g., long-term habitat processes). Instead the focus is on the goal of "maintaining or improving" existing habitat for important fisheries throughout the state.

Guidance for selecting streams to evaluate statewide was provided by the Wyoming Game and Fish Department (WGFD), Water Management Plan (Annear and Dey 2006). The five-year plan identified and prioritized high quality habitats for instream flow studies and identified native Yellowstone cutthroat trout (YSC; *Oncorhynchus clarkii bouvieri*) and Snake River cutthroat trout (SRC; *Oncorhynchus clarkii behnkei*) as the greatest priority species for this planning period. The plan identified the Greys-Hoback watershed as the highest priority for conducting instream flow studies.

Yellowstone cutthroat and SRC were prioritized for instream flow studies, in part, because these cutthroat trout subspecies were recently considered for federal listing as threatened or endangered. Between 1998 and 2006, there were several actions regarding these two subspecies, including a decision to treat the two as "a single entity" (Federal Register 2001, Federal Register 2006). The most recent finding of the U.S. Fish and Wildlife Service was that the species (aggregate of both subspecies) does not warrant listing (Federal Register 2006). In response to the petition for federal listing of YSC, the WGFD developed significant, targeted management efforts to protect and expand habitat and populations of both YSC and SRC within their historic range (WGFD 2005a) and has participated in multi-state strategic planning efforts (Range-Wide YCT Conservation Team 2009a, 2009b).

Yellowstone cutthroat trout historically occupied Wyoming waters in the Snake River and Yellowstone River drainages, including the tributary Wind/Bighorn and Tongue River drainages (Behnke 1992, Kruse et al. 1997, Dufek et al. 1999, Kruse et al. 2000, May et al. 2003). The range of SRC occurs within the range of the more widely distributed YSC and includes the headwaters of the Snake River and its tributaries (Van Kirk et al. 2006, May et al. 2007). Debate continues about whether YSC and SRC are distinct subspecies (Van Kirk et al. 2006, Sweet 2009). Leary et al. (1987) was not able to differentiate the two subspecies using genetics and Kruse (1998) did not find meristic differences (counting features such as fins rays or scales) between the two subspecies. However, there are morphological distinctions that are not typically found in the same watersheds, so the WGFD manages them separately (Gipson 2006, Sweet 2009).

The prioritization of watersheds and streams for instream flow studies in Wyoming was based on available information on YSC and SRC populations, including genetic status and population demographics. A range-wide status assessment conducted by fisheries biologists from Wyoming, Montana, and Idaho (May et al. 2003, May et al. 2007) identified conservation populations and assessed the relative extinction risk among populations. Of the extant populations in Wyoming, those in the Greybull River, Wood River, and East Fork Wind River were believed to contain genetically pure populations that span a large geographic area (Kruse et al. 2000) and these streams were targeted for instream flow studies during 1997 through 2006. The next watershed in priority was the Greys-Hoback and tributaries of these two rivers. These were identified as high priority streams for instream flow studies because much of the watershed contains SRC populations of high genetic purity. Since genetic status of SRC was similar throughout this watershed (predominantly unaltered; Novak et al. 2005), individual streams were selected based on current understanding of their importance to the local SRC population in terms of contributing to the long-term persistence of the population (e.g., does a stream contain regularly-used spawning habitat?), the length of stream (longer streams provide greater protection for level of effort expended), and the ease of logistics (streams selected in a small geographic area for a given year can be more efficiently studied). From 2008 through 2010 studies were conducted on the Hoback River and its tributaries, and in 2010 a study was also conducted on the Little Greys River.

Objectives

The objectives of this study were to 1) quantify year-round instream flow levels needed maintain SRC habitat and 2) identify a channel maintenance flow regime that will maintain long-term trout habitat and related physical and biological processes (Appendix B). The audience for this report is broad and includes the State Engineer and staff, the Water Development Office, aquatic habitat and fishery managers, and non-governmental organizations, and individuals interested in instream flow water rights, SRC management, or in the Greys River watershed.

Study Area

The Greys River enters the Snake River at Alpine, Wyoming (Figure 1). The basin is classified with the 5th level hydrologic unit code (HUC) of 1704010305. The Greys watershed includes an area of 455 square miles, which is about 10% of the Snake River headwaters basin (HUC 170401) area. Land ownership in the watershed includes 99.9% public lands, all Forest Service lands. Recreational uses in the drainage include wildlife observation, hiking, fishing, camping, hunting, floating the river, horseback riding and packing, cross country skiing, snow machine riding, and snowshoeing.

The Greys River basin elevation ranges from 5,700 ft to 11,393 ft above sea level at Wyoming Peak. There are several tributaries in the Greys watershed where alpine glaciation resulted in U-shaped valleys (Rosgen valley type V) and others with more gradual sloping sides (Rosgen type II). Stream channels throughout the Greys River basin would be primarily classified as Rosgen type “B” and “C” from inspection of 1:24,000 scale topographic maps.

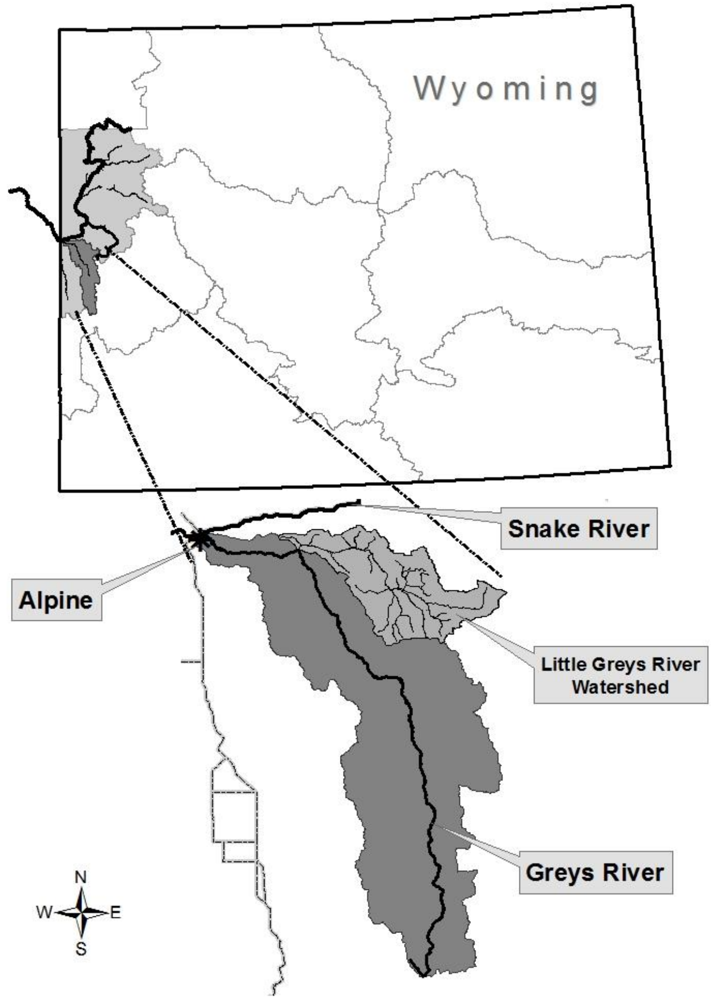

FIGURE 1. Location of Little Greys River, Wyoming (HUC 170401030510) in the Greys River watershed.

Annual precipitation in this watershed averaged 22.0 inches over the period 1895–2010 according to data from the PRISM Climate Group, Oregon State University (PRISM 2012). Approximately 30 percent of all the precipitation falls as snow with over 300 inches of total accumulation (BTNF 2004). The average minimum air temperature was 25.7°F and the average maximum was 51.7°F from 1895–2010. Winter conditions typically result in widespread frazil and anchor ice development, which may impact over-winter habitat for fish.

As part of its strategic habitat plan (SHP), the WGFD has prioritized the Greys River watershed as an "*enhancement habitat area*" for aquatic habitat (WGFD 2009). According to the SHP, enhancement areas "*are important wildlife areas that can or should be actively enhanced or improved by WGFD and partners over the next few years if opportunities exist*."

Hydrology

The reference gage used for estimating hydrology for the ungaged study site was the Greys River gage (13023000), which has been in continuous use since 1953. Stream flow at the Greys River gage is typical of snowmelt runoff streams with short periods of high (runoff) flow and a substantial portion of the annual flow as a low (base) flow (Figure 2). Annual peak flow occurred between May 1 and June 15 over the period of record (median date was May 28). Base flow recession occurs throughout summer with near base flow levels attained by September. Annual flow minima occurred in winter (December, January, or February [Figure 3]).

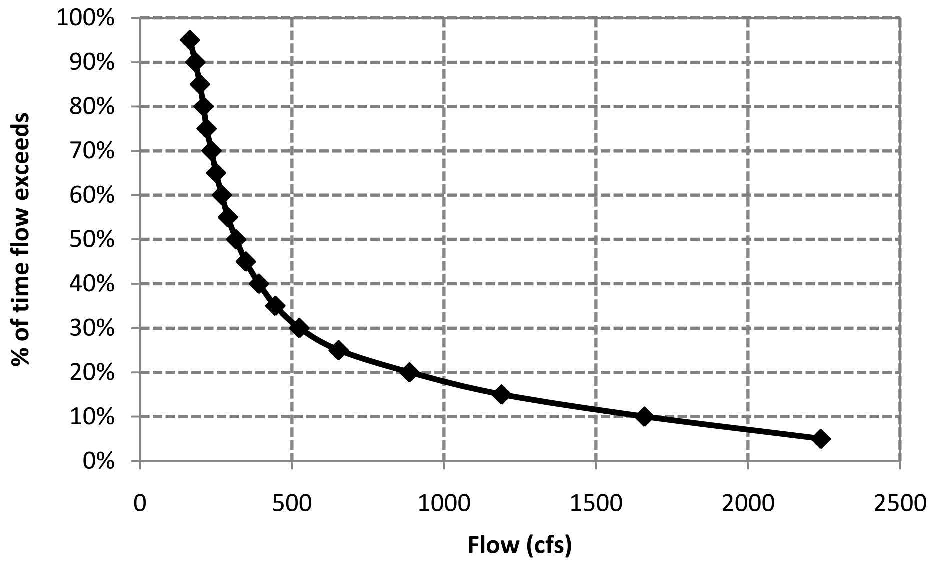

FIGURE 2. Flow exceedance curves for the Greys River USGS stream gage station (13023000) over the period 1953-2012.

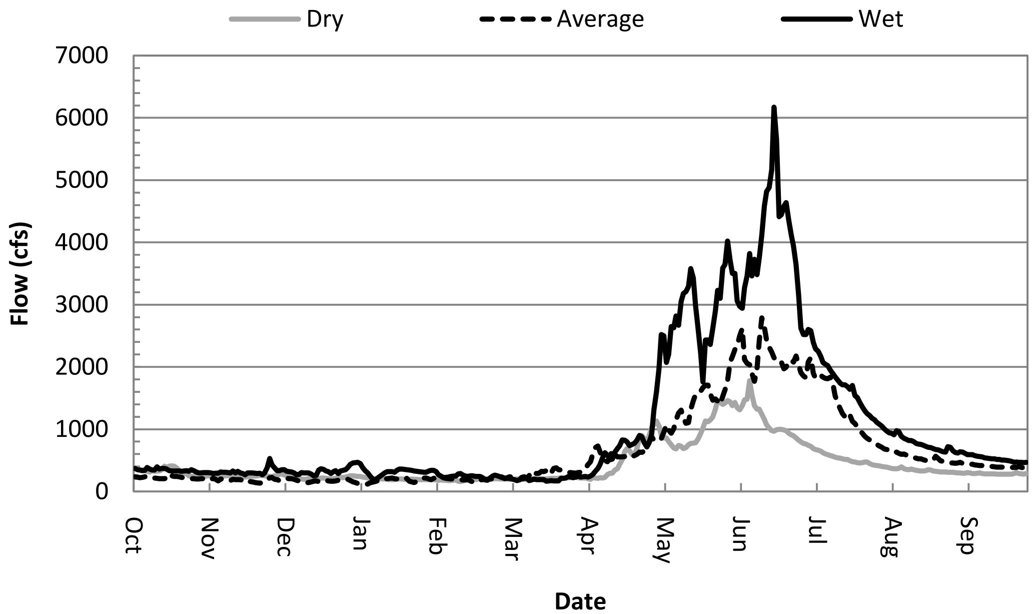

FIGURE 3. Hydrographs for representative wet (1971), average (1995), and dry (1981) water years from the Greys River USGS stream gage station (13023000). Representative years were randomly selected from within each of three flow exceedance classes (wet 0–10%, average 30–70%, and dry 90–100%; HabiTech 2009).

Biology

<u>Fish and Other Aquatic Resources</u>

The fish community in the Greys River basin includes two native game species, SRC and mountain whitefish (MWF; *Prosopium williamsoni*). Other native species include mountain sucker (MTS; *Catostomus platyrhynchus*), Utah sucker (UTS; *Catostomus ardens*), Bonneville redside shiner (RSS; *Richardsonius balteatus*), Pauite sculpin (PSC; *Cottus beldingi*), and mottled sculpin (MSC; *Cottus bairdi*). Introduced brook trout (BKT; *Salvelinus fontinalis*), brown trout (BNT; *Salmo trutta*), and rainbow trout (RBT; *Oncorhynchus mykiss*) are also found in the watershed. The most abundant species captured during WGFD sampling efforts in the Little Greys River was SRC and PSC, but MSC, MWF, and UTS were also common (WGFD 2010). The current management objective in the Greys River basin is to maintain a wild population of SRC.

Habitat preferences of target species, and their life stages, are an important component of instream flow studies since flow recommendations are based on maintaining sufficient habitat for target species to carry out life history functions (e.g., growth and reproduction). Species-specific habitat preferences are used to develop habitat suitability curves that are in turn used in PHABSIM and River 2D models (described below). Most research on habitat use has focused on YSC (perhaps including SRC in some cases since the two are not always differentiated). However, since SRC are genetically very similar, it is likely that they behave similarly to YSC in regards to habitat preferences and reproduction. Dey and Annear (2006) found that adult YSC in

Trout Creek (tributary of the North Fork Shoshone River) were most commonly found in areas with depths of 1.15–1.60 ft and average column velocities of 0.36–1.91 ft/s. For juvenile YSC, these ranges were slightly different with depths of 1.0–1.5 ft and average column velocities of 0.38–1.65 ft/s (Dey and Annear 2006). Most growth of adult and juvenile SRC occurs during the relatively short summer and early fall periods. Habitat for these life stages is also critical during winter to allow over-winter survival.

In addition to adults and juveniles, two other life stages were evaluated for habitat availability, spawning adults and fry. YSC and SRC generally spawn between March and July depending on local hydrology and water temperatures (believed to be triggered around 41ºF; Kiefling 1978, Varley and Gresswell 1988, De Rito 2005). The stream gradient observed in spawning areas is usually less than 3% (Varley and Gresswell 1988), but non-migratory fluvial populations have been documented in streams with a mean gradient of 6% (Meyer et al. 2003). Spawning activity for YSC and SRC in Wyoming has been observed during May and June in watersheds within the Big Horn River Basin in north central Wyoming (Greybull River, Shoshone River and their tributaries; Kent 1984, Dey and Annear 2002, Dey and Annear 2006). Elevation influences the timing of spawning in YSC and SRC; stream segments located at higher elevations more likely to remain colder and cause both spawning and egg incubation to occur later in the summer. Dey and Annear (2003) found that spawning occurred into July in streams above approximately 8,000 ft in elevation (in the Greybull watershed) and extended recommendations for spawning flows through July 15 in such high elevation sites. The upstream boundary of the Little Greys River instream flow segment is about 7,500 ft in elevation. It is possible that spawning may extend into July in the very upper portion of the watershed (above the segment), but most activity in the segment likely occurs in June. Dey and Annear (2006) were unable to observe statistically acceptable numbers of spawning YSC (n=4) to develop habitat suitability curves for spawning YSC and SRC in Wyoming and did not search for fry. Spawning YSC habitat suitability data from a Snake River tributary in Idaho are presented in Thurow and King (1994); they found that velocity preference ranged from 1.12 to 1.72 ft/sec and depth preference from 0.52 to 0.82 ft.

Fry habitat data for Colorado River cutthroat (*Oncorhynchus clarkii pleuriticus*; CRC) in Wyoming (Bozek and Rahel 1992) were used in the absence of any data available for YSC or SRC. The velocity range most often used by CRC fry was less than 0.1 ft/sec and the depth range was 0.36 to 0.49 ft. Fry are most likely to be present during July, August, and September in the Greys River watershed.

Geomorphology

Maintaining appropriate stream channel characteristics in a given stream reach is important for maintaining fish habitat throughout that stream. Channel form is a direct result of interactions among flow regimes (Schumm 1969), sediment loads (Komura and Simmons 1967), and riparian vegetation, which are in turn a direct function of the form and condition of the watershed (Leopold et al. 1964; Heede 1992; Leopold 1994). For many alluvial streams in their natural state, the channel exists in a state of dynamic equilibrium in which the sediment load is balanced with the stream's transport capacity over time (Bovee et al. 1998). When sediment load exceeds transport capacity, aggradation or other alteration of channel form will occur. When transport capacity exceeds sediment load, the channel may adjust through widening the channel or degrading the bed.

A natural range of flows, including occasional high flow, is that it maintains diverse riparian and floodplain vegetation and, in turn, provide suitable conditions for the community of animals that use these habitats. An effective instream flow regime should include these higher flows that maintain the channel form and habitat conditions for fish over the long term. These flows sustain the river channel conditions by permitting a connection to the floodplain, preventing buildup of fine sediments, and facilitating a variety of other important ecological processes (Carling 1995, Annear et al. 2004, Locke et al. 2008). Any time water is extracted from a stream this condition changes; larger quantities of extraction have a greater impact on natural processes.

Physical changes in the stream caused by road building, culvert addition, riparian habitat reduction, and other impacts also affect the ability of the stream to sustain effective sediment transport and regenerate riparian plant communities. Additional streambank instability and sediment inputs result from land management practices (grazing and channel alterations) and road construction and maintenance activities in the watershed. The resulting streambank instability, channel widening and high sediment loads promote unstable stream channel dynamics that limit pool development and increase stream channels dominated by long series of runs and riffles. A lack of pool-forming large woody debris in many locations also contributes to a lack of pools. However, where large woody debris is abundant pools are more common. Also, beaver activity enhances instream habitat complexity in some locations.

The current interpretation of the instream flow statute does not consider high flows that are important for channel maintenance to be necessary to support a fishery. These high flows have a critical influence on physical habitat conditions in a stream and if substantially reduced would have negative impacts on habitat, riparian assemblage of plants and animals, and ultimately the resident fishery (Stromberg and Patten 1990, Rood et al. 1995, Mahoney and Rood 1998). Recommendations for flows sufficient to allow channel maintenance and provide a more complete flow pattern that fully maintains fishery habitat are presented in Appendix B. Should opportunities arise in the future to secure instream flow water rights for long-term maintenance of fluvial geomorphic processes, this information may provide a valuable reference.

Water Quality

Water quality is a critical component of any fishery. The Wyoming Department of Environmental Quality rates the Little Greys River as a “Class 2AB” water. According to their classification system (WYDEQ 2007), “*Class 2AB waters are those known to support game fish populations or spawning and nursery areas at least seasonally and all their perennial tributaries and adjacent wetlands and where a game fishery and drinking water use is otherwise attainable. Unless it is shown otherwise, these waters are presumed to have sufficient water quality and quantity to support drinking water supplies and are protected for that use. Class 2AB waters are also protected for nongame fisheries, fish consumption, aquatic life other than fish, recreation, wildlife, industry, agriculture and scenic value uses*.” As noted above, high sediment loads are common which increases turbidity during runoff and after rain events.

Connectivity

Connectivity of a river system refers to the ability of fish and other organisms to navigate between habitats to complete each portion of their life cycles. However, it is more than that. Connectivity of a stream system also incorporates the pathways that move energy and matter through the system. River system connectivity is manifested along four dimensions: longitudinal, lateral, vertical, and time (Ward 1989). Lateral connectivity is critical to the functioning of floodplain-based stream ecosystems because of the transport of nutrients and organic matter from the floodplain to the stream during floods. This process often drives development of aquatic food elements that affects productivity of the fish. Seasonal flooding of unregulated streams creates and maintains diverse species of riparian vegetation (Nilsson et al. 1989), which, in turn, fosters diverse animal communities both within and adjacent to the stream channel.

The Greys River and its tributaries have few barriers restricting flow in the stream channels. There are no large dams in the watershed, but a few small diversion structures and culverts that affect fish passage and flow pathways. Access to the floodplain is good throughout the watershed and is only restricted in areas with canyon walls and naturally limited floodplain development.

Methods

Instream Flow Segment and Study Site Selection

One stream segment is proposed for an instream flow water right filing in the Little Greys River (Figure 4; Table 1). The boundaries for the segment were identified after considering land ownership, hydrology, and stream channel characteristics. Within the stream segment, instream flow recommendations were developed for individual life stages of SRC (fry, spawning, juvenile, and adult). Securing instream flow water rights on this stream segment will help ensure the future of SRC and other important fish species in Wyoming by protecting existing base flow conditions in priority against potential, but presently unidentified, future consumptive and diversionary demands.

Instream flow segments are nearly always located on public land where unappropriated water remains, and the public has access to the fishery. However, in some instances landowners that are nearby or adjacent to a proposed segment are given the opportunity to request that the state extend an instream flow segment on the portion or portions of any streams crossing their property. Such requests are strictly voluntary and must be made in writing to the department. Regardless of whether instream flow segments are placed entirely on public lands or include private segments, instream flow water rights are junior to existing water rights in the stream and will not affect their lawful use in any way.

The instream flow segment selected on the Little Greys River is located entirely on public land. Because there were no nearby private property sections, there was no need to contact individual landowners and assess interest in extending the proposed segment through private lands. However, interested landowners in this watershed may contact the WGFD to evaluate opportunities for including potential segments through their property under the present proposal. Separate, new studies would be needed should downstream private landowners decide to seek an instream flow right through their property in the future. The department has no plans to conduct such studies at the present time.

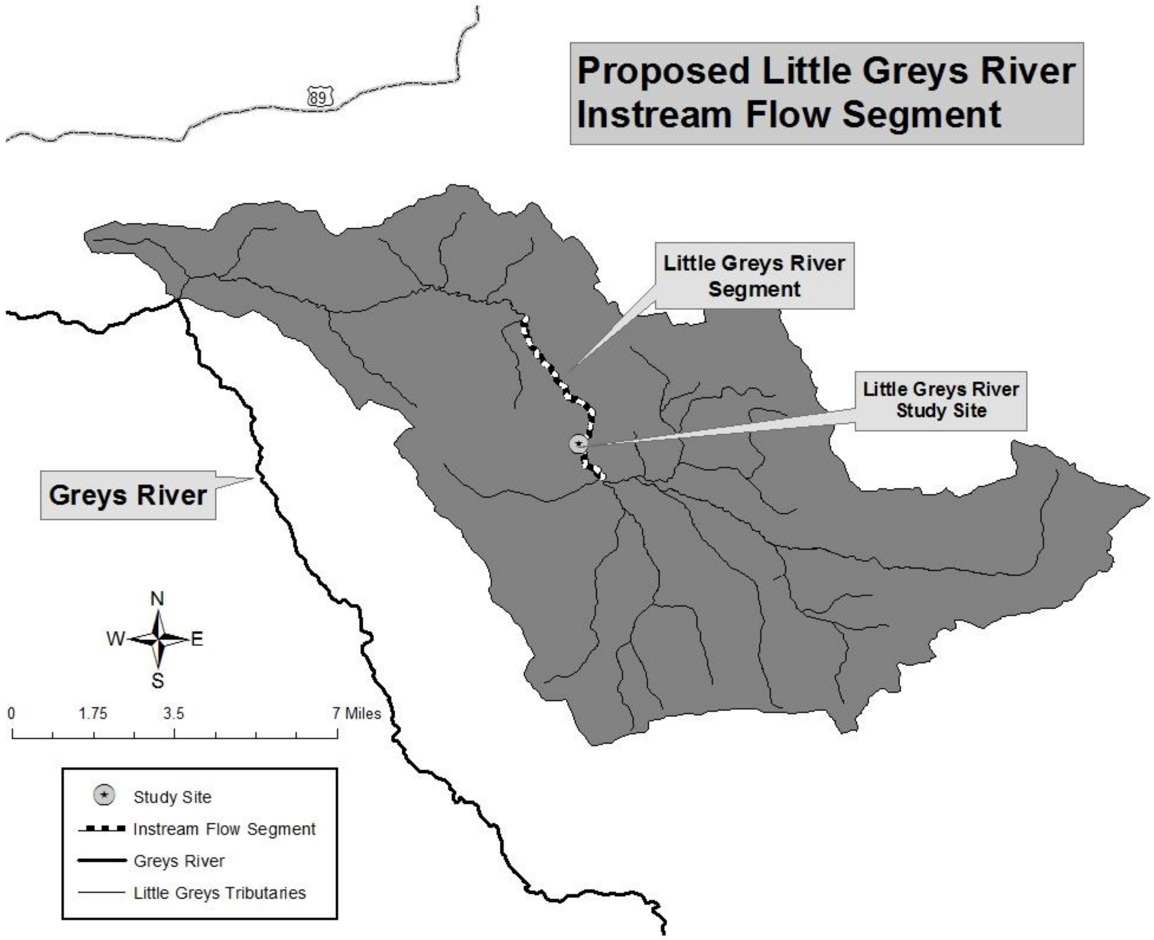

FIGURE 4. Data were collected to evaluate fish habitat at one potential instream flow segment on the Little Greys River.

TABLE 1. Location and length of the proposed instream flow segment on the Little Greeys River. Coordinates and elevations are provided for the downstream end of the segment and are UTM Zone 12, NAD83 datum.

Segment	Description	Length (mi)	Easting	Northing	Elevation (ft)
Little Greys River	Upstream from Bull Hollow to the confluence with South Fork Creek	4.5	519120	4776487	6,440

One study site (approximately 450 ft long) was selected to represent the Little Greys River instream flow segment (Figure 5). The bankfull width in this reach was approximately 59 ft. The study site is shorter than that recommended by Bovee (1982; 10-14 times the channel width), but habitat above and below the chosen site were long stretches of uniform run habitat that would not have improved the representativeness of the site if included. The complexity of this site is representative of the range of habitat conditions available in the instream flow segment. All data collection was conducted in this study site and extrapolated to the entire proposed instream flow segment. These data were analyzed to determine the availability of suitable habitat for all life stages of SRC at various flow conditions.

FIGURE 5. The Little Greys River study site at a discharge of 47 cfs.

Hydrology in the Instream Flow Segment

Development of flow recommendations for an instream flow study segment requires an understanding of local stream flow conditions. In most cases stream gage data are not available within the segment and the data must be derived from a regional reference gage. That is the case for the Little Greys River since there were no localized stream gage data available. The reference gage used for the instream flow segment in the Little Greys River was the Greys River USGS gage (13023000) with data available from 1938 through 2012; the gage was in continuous operation between 1953-2012

Similar to previous efforts (HabiTech 2009), mean annual flow (also called “average daily flow” or ADF), annual flow duration, monthly flow duration, and flood frequency were estimated for the proposed instream flow segment. HabiTech (2009) calculated average daily flows from the contributing basin area models of Miselis et al. (1999) and Lowham (1988) and determined that neither accurately predicted flows at the reference gage. Alternative models using channel geometry (bankfull width) by Lowham (1988) and Miselis et al. (1999) yielded more accurate estimates of the reference gage with the former being the best. The bankfull width at the downstream end of the Little Greys River instream flow reach was used for the model calculations.

A dimensional analysis approach was used to develop both annual and monthly flow duration information. Dimensionless duration tables were created for the reference gage by dividing each duration class by the mean annual flow. The dimensionless flow value for each annual and monthly percentile was then multiplied by the estimated average annual flow for the instream flow segment to develop flow duration values for the segment. A similar approach was used to develop the flood frequency series. For further details on the procedures used, see HabiTech (2009).

Average daily flow estimates were used in applying the Habitat Quality Index and Habitat Retention models (described below). The 1.5-year return interval on the flood frequency series was used to estimate bankfull flow (Rosgen 1996) for use in the Habitat Retention model and for developing channel maintenance flow recommendations (Appendix B). Channel maintenance calculations also used the 25-year peak flow estimate from the flood frequency analysis. The monthly flow duration series was used in developing winter flow recommendations. Throughout this report, the term "exceedance" is used, as in "20% exceedance flow." The 20% exceedance flow refers to the flow level that would be exceeded 20% of the time or that would be available approximately one year out of every five consecutive years. Flow measurements collected by WGFD during instream flow habitat studies were used to help validate the models and enhance the accuracy of the hydrological estimates.

Biology – Fish Habitat

Availability of fish habitat is evaluated using several different habitat models for a study site. "Habitat" in this report refers the combination of physical conditions (depth, velocity, substrate, and cover) for a given area. These physical conditions vary with discharge. It is important to note that these variables do not represent a complete account of all variables that comprise trout habitat. Habitat for trout also includes environmental elements such as water temperature, dissolved oxygen, and other variables. These other variables are important, but are not included in models used for these analyses because they do not fluctuate with changes in the quantity of flow as predictably as the physical habitat parameters and thus were assumed to be constant over the range of flows analyzed. Interpretation of model results based on these physical habitat parameters assumes that this subset of trout habitat is important and provides a reasonable estimate of habitat availability at each flow and ability of trout to persist on a short-term basis.

River2D Model

Habitat modeling has been used extensively for developing instream flow recommendations since inception of the PHABSIM model in the 1970s (Stalnaker et al. 1995, Bovee et al. 1998). However, two-dimensional models, such as River2D, have received increasing attention and use (Ghanem et al. 1994, 1996, Bovee et al. 2008). These tools generate depth and velocity predictions throughout study reaches as opposed to the one-dimensional transect-based output that simulates physical habitat only in a longitudinal dimension. The end result of total area of useable habitat (weighted usable habitat; WUA) is similar to PHABSIM, but the results are finer scaled and present a much more detailed characterization of habitat availability throughout the study site. The model is also able to predict conditions around complex habitats like multiple channels and eddies that are impossible or extremely complicated with a transect-based dataset. The two-dimensional model also generates habitat depictions that ease interpretation of the spatial relationships of habitat availability. The River2D model (Steffler and Blackburn 2002) was employed in the study segment.

One of the primary differences between PHABSIM and River2D models is that the latter entails development of a detailed map of elevation and substrate data of the stream channel bed and banks. The model uses the detailed elevation map and stage discharge relationship (developed at the downstream boundary) to move water through the site at a given discharge and allow estimates of depth and velocity at any location. We collected all bed elevation points (northing, easting, and elevation) for the River2D model site with a TopCon model 211D total station. Boulders were surveyed using a model where three points where recorded in the field (following the longest axis) and width and shape of the boulder recorded. Data for each boulder were put in the model to generate a series of points that more accurately represented each boulder and these points were put into the River 2D elevation map. Substrate was mapped throughout the site using the categories vegetation, mud, silt, sand, gravel, cobble, boulder, and bedrock. The percentages of dominant and subdominant classes were assigned to each mapped area.

Once a working model was developed from substrate, elevation, and discharge data, it was calibrated to improve predictions of depth and velocity throughout the study site. Calibration was done by attempting to match predicted water surface elevation throughout the site to data collected at each of several discharges. The primary tool for this calibration is adjusting roughness to minimize the average difference between the predicted and measured water surface elevations at several points throughout the study site. Adjustments were made to roughness values as needed to achieve the best possible model fit with the available data. When the model was calibrated at a given discharge it was then run at another calibration discharge and further modified until it worked well at both discharges. This process was repeated for all calibration discharges. A second, fine-scaled, calibration step involved comparing observed depths and velocities (collected at randomly spaced points) to predicted values at a calibration discharge and adjusting roughness to further refine the model fit. With each adjustment, all calibration discharges were re-run with the new roughness values to determine change to each.

The final result was a single calibrated model that was run at several discharges over the evaluation range. The calibrated model was used to simulate physical conditions in the study reach and estimate WUA for each SRC life stage at each discharge. The results are evaluated in terms of the "peak" of habitat availability over the range of modeled discharges.

Habitat Retention Model

We used the Habitat Retention Method (Nehring 1979, Annear and Conder 1984) to identify the flow that maintains specified hydraulic criteria (Table 2) in riffles. Maintaining depth, velocity, and wetted perimeter criteria in riffles is based on an assumption that other habitat types like runs or pools remain viable for fish when adequate flows are provided in shallow riffles that serve as hydraulic controls (control water surface elevations for the pools and runs immediately upstream of the riffle) (Nehring 1979).Flow recommendations derived from the Habitat Retention Method describe instream flows needed to maintain fish passage between habitat types and benthic invertebrate survival at any time of year when the recommended flow is naturally available. The flow identified by the Habitat Retention Method is important year round, except when higher instream flows are required to meet other fish life history needs or fishery management purposes.

Simulation tools and calibration techniques used for hydraulic simulation in PHABSIM are also used with the Habitat Retention approach. The difference is that Habitat Retention does not translate depth and velocity information into conclusions about incremental changes in the amount of physical space suitable for trout life stages. The Habitat Retention method focuses on identifying riffle hydraulic characteristics that maintain fish passage and invertebrate production. The AVPERM model within the PHABSIM methodology is used to simulate cross section depth, wetted perimeter, and velocity for a range of flows. The flow that maintains two out of three criteria (Table 2) for all three transects is then identified; however, because of the critical importance of depth for maintaining fish passage, the 0.2 ft threshold must be one of the criteria met for each transect.

TABLE 2. Hydraulic criteria for determining maintenance flow with the Habitat Retention method in streams up to 20 ft wide. For streams with a mean bankfull width greater than 20 ft the mean depth criteria is the product of 0.01 times mean bankfull width.

Category	Criteria
Mean Depth (ft)	0.20
Mean Velocity (ft/s)	1.00
Wetted Perimeter[a] (%)	50

a - Percent of bankfull wetted perimeter

Habitat Quality Index Model

We used the Habitat Quality Index (HQI; Binns and Eiserman 1979, Binns 1982) to determine relative trout habitat suitability or production potential over a range of late summer (July through September) flow conditions. Most of the annual trout production in Wyoming streams occurs during the late summer, following peak runoff, when longer days and warmer water temperatures facilitate growth. The HQI was developed by the WGFD to provide an index of relative habitat suitability, which is correlated to trout production as a function of nine biological, chemical, and physical trout habitat attributes. Each attribute is assigned a rating from 0 to 4 with higher ratings representing better trout habitat features. Attribute ratings are combined in the model with results expressed in trout Habitat Units (HU's), where one HU is defined as the amount of habitat that will support about 1 pound of trout, though the precise relationship can vary between streams. HQI results were used to identify the flow between July 1 and September 30 needed to maintain existing levels of adult and juvenile Yellowstone cutthroat trout production (habitat quality) and are based on an assumption that flow needs for other life stages are adequate at all other times of year. The model also assumes that water quality is not a limiting factor.

In the HQI analysis, habitat attributes measured at various flow events are assumed to be typical of late summer flow conditions. For example, stream widths measured in June under high flow conditions are considered an estimate of stream width that would occur if that flow level were a base flow occurring in September. Under this assumption, HU estimates are extrapolated through a range of potential late summer flows (Conder and Annear 1987). Some attribute ratings were mathematically derived to establish the relationship between discharge and trout habitat at discharges other than those measured. In calculating Habitat Units over a range of discharges, temperature, nitrate concentration, invertebrate numbers, and eroding banks were held constant.

Article 10, Section d of the Wyoming Instream Flow statute states that waters used for providing instream flows "*shall be the minimum flow necessary to maintain or improve existing fisheries*." The HQI is used to identify a flow to maintain the existing fishery in the following manner: the number of habitat units that occur under normal July through September flow conditions is quantified and then the flow that maintains that level of habitat is identified. There are two reference conditions that are used to estimate normal summer flow levels and habitat conditions. The August 50% monthly exceedance flow is the primary reference condition that is targeted by the flow recommended for habitat maintenance in the target reach, but the evaluation also includes a review of the September 20% monthly exceedance flow (which is often similar to the August 50% exceedance flow) to indicate late summer flow conditions that occur less frequently, but still approximately one year out of every five. Both flow conditions are important for maintaining habitat for the existing fishery. Neither represents the minimum flow needed to keep the target fish species alive, but are used to identify a flow condition that provides the least amount of water needed to realize the statutorily authorized beneficial use of maintaining the existing fishery.

Natural Winter Flow

The three habitat modeling approaches described above are not well suited to determine flow requirements during ice-prone periods (October through early April). These methods were developed for, and apply primarily to, open-water periods. Ice development during winter months can change the hydraulic properties of water flowing through some stream channels and compromise the utility of models developed for open water conditions. The complexities of variable icing patterns make direct modeling of winter trout habitat over a range of flows difficult if not impossible. For example, frazil and surface ice may form and break up on multiple occasions during the winter over widely ranging spatial and temporal scales. Even cases that can be modeled, for example a stable ice cap over a simple pool, may not yield a result worthy of the considerable time and expense necessary to calibrate an ice model. There are no widely accepted aquatic habitat models for quantifying instream flow needs for fish in under-ice conditions (Annear et al. 2004). As a result, a different approach was used to develop recommendations for winter flows.

For Wyoming headwater streams, a conservative approach is needed when addressing flow requirements during harsh winter habitat conditions. Scientific literature indicates that stressful winter conditions for fish would become more limiting if winter water depletions were to occur. Even relatively minor flow reduction at this time of year can change the frequency and severity of ice formation, force trout to move more frequently, affect distribution and retention of trout, and reduce the holding capacity of the few large pools often harboring a substantial proportion of the total trout population (Lindstrom and Hubert 2004). Hubert et al. (1997) observed that poor gage records often associated with the winter season requires use of a conservative value. The 50% monthly exceedance does not provide an appropriate estimate of naturally occurring winter flow. It is more appropriate from the standpoint of maintaining fisheries to recommend the higher flows of a 20% monthly exceedance. Such an approach assures that we recommend flow approximating the natural winter condition even in cases where flow availability is prone to being underestimated due to poor gage records or other estimation errors. This approach has been used for many recent instream flow recommendations (e.g., Dey and Annear 2006, Robertson and Dey 2008) and likewise, was adopted for the instream flow segment on the Little Greys River.

Geomorphology

The geomorphology of the proposed instream flow segment was evaluated by visual observation of physical habitat conditions and by evaluating the current flow characteristics. In addition, we conducted a detailed assessment of channel maintenance flow requirements for the stream (Appendix B).

Water Quality

No detailed assessment of water quality was conducted as part of this study because water quality conditions throughout the Hoback River watershed are considered excellent (WYDEQ 2001). A review of data stored in the EPA STORET database was conducted to reveal any anomalies in reported data, and a temperature logger was installed in the study site during summer data collection. Based on this review, the water quality condition was considered to be in very good condition at this time, but could potentially deteriorate with any substantial reduction in flow in ways that are difficult to predict.

Connectivity

In developing instream flow recommendations for Dell Creek, the presence of barriers to connectivity were considered for physical, chemical, and even biological conditions in all four dimensions. The Habitat Retention Method was used to quantify the flow needed to maintain continuous hydrologic connectivity within the stream channel. No detailed assessment was conducted to quantify flows needed to maintain lateral connectivity nor was an assessment done to evaluate the relationship between ground water and flow (vertical connectivity). An evaluation of the ability of the stream to transport nutrients, energy and sediments was beyond the scope of this study due to the level of effort required to evaluate such processes, but it is an important aspect to a properly functioning stream environment.

Instream Flow Recommendations

Wyoming statute 41-3-1001-1014 declares that instream flows may be appropriated for maintaining or improving fisheries. This statute has been interpreted by the Wyoming State Engineer's Office to include only the hydrology and biology (fisheries) riverine components. The law does not specifically provide that other widely accepted components of a fishery including geomorphology, water quality, or connectivity may serve as a basis for quantifying flow regime needs for fisheries. As a result, the instream flow recommendations generated in this report provide a good means of ensuring that physical habitat will be available for SRC in the Little Greys River for the near term. Over a longer temporal scale, a flow regime that does not provide sufficient flow at appropriate times of year to maintain the necessary geomorphology, water quality, or connectivity conditions will likely not achieve the statutorily authorized beneficial use of maintaining the existing fishery in perpetuity. The analyses presented in this report indicate what flows provide suitable hydraulic habitat within this existing channel form, but the channel form may change over time.

Within the constraints described above, we recommend instream flows for the Little Greys River during four seasonal periods, which are based on SRC biology and Greys River hydrology (Table 3; Figure 6). Over-winter survival of adult and juvenile SRC was addressed with natural winter flow from October 1 through March 31. The hydrograph indicates that, on average, relatively low base flow conditions in winter persist through March 31 during both the highest and lowest flows recorded in the Greys River. Habitat for juvenile and adult SRC is evaluated using RIVER2D habitat modeling for the early spring connectivity period, which occurs prior to spawning during the rising limb of spring runoff from April 1 to April 30. Spawning and incubation habitat for SRC was evaluated with habitat modeling results for the spawning lifestage using RIVER2D for the period May 1–June 30. Summer habitat for growth and production of fry and juvenile SRC was evaluated with Habitat Quality Index results (adult SRC habitat) and modeling results from RIVER2D for the period July 1–September 30. The Greys River hydrograph indicates that during low water years, there is little variation between flows in the early and late parts of this seasonal period (Figure 6).

TABLE 3. Snake River cutthroat trout life stages and seasons considered in developing instream flow recommendations. Numbers indicate the method used for each combination of season and life stage, and grey shading indicates the primary data used for flow recommendations in each season.

Life stage and Fishery Function	**Over-Winter Oct 1 – Mar 31**	**Early Spring Apr 1 – Apr 30***	**Spring May 1 – Jun 30***	**Summer Jul 1 – Sep 30**
Survival of all life stages	1			
Connectivity between habitats	2	2	2	2
Adult and juvenile habitat availability	3	3	3	3
Spawning habitat availability		3	3	
Fry habitat availability				3
Adult and juvenile growth				4
Habitat maintenance for all life stages*		5	5	

1=Natural winter flow or Habitat Retention, whichever is greater, 2=Habitat Retention, 3=River 2D Simulation, 4=Habitat Quality Index, 5=Channel Maintenance.

* Channel maintenance flow recommendations are presented in Appendix B.

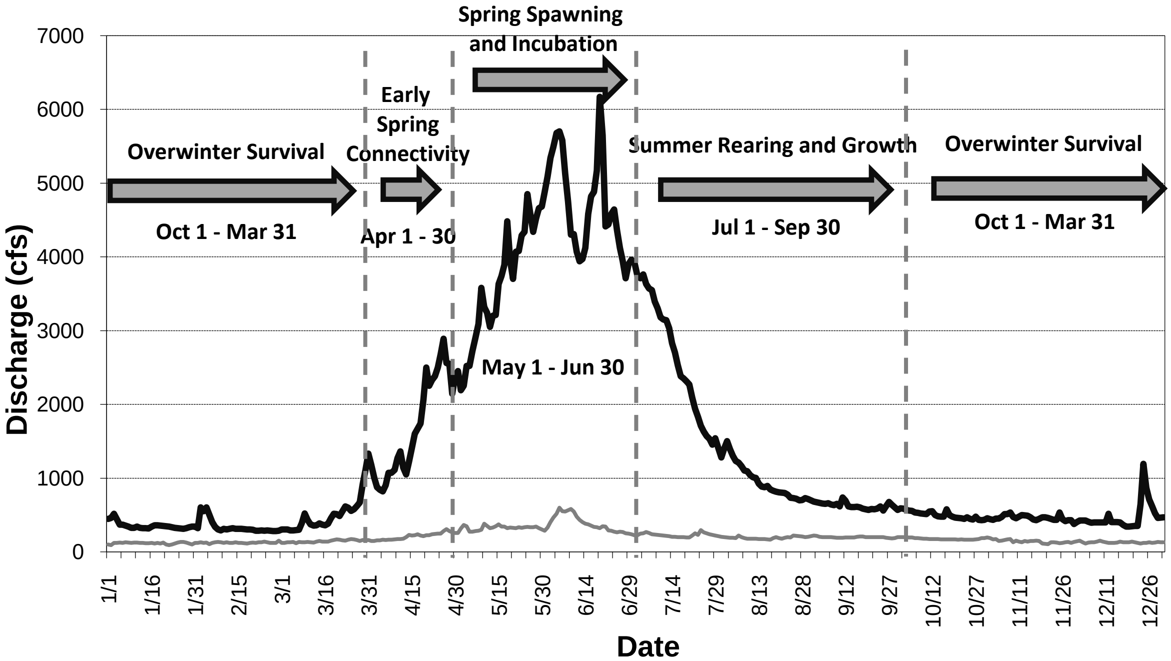

FIGURE 6. Minimum and maximum daily historical discharge values in the Greys River and critical time periods for SRC. Data are from USGS gage 13023000 on the Greys River (1938–2012).

A combination of several different methods was used to develop instream flow recommendations to maintain or improve the fishery (biological riverine component) in the Greys River. When possible, data were collected to run each of several habitat models for the study site (including the PHABSIM or River 2D habitat model, the Habitat Retention model, and the Habitat Quality Index model). However, the ecological characteristics and issues at the study site were sometimes unique and not necessarily appropriate for scaling up to the entire segment. As a consequence, the models used for developing a recommendation were selected based on their appropriateness for the characteristics and flow needs at the site. These models provide an evaluation of physical habitat for trout, thus flow recommendations based on these analyses were chosen to maintain sufficient habitat, which is defined as water depth, velocity, and cover necessary for each fish species and life stage of interest. Recommended flows were designed to protect habitat during portions of the year that are most critical to a given species and life stage. Recommendations were also evaluated relative to natural flow conditions, but because the instream flow segment did not have stream gage data, estimates of stream flow were developed for comparison.

When two or more methods could be used for a recommendation, the method chosen was the one that yielded the higher flow needed for a particular fishery maintenance purpose. For example, the Habitat Retention approach may provide a base flow that is too low to maintain sufficient habitat for all life stages and is not used for instream flow recommendations when other aspects of fishery maintenance require higher flows. When habitat is maximized at flows greater than the natural 20% exceedance flow, the latter will be used as a maximum recommended instream flow. Channel maintenance flows perform their function during runoff in April, May, June, and July (Appendix B) but are not used in the instream flow water right application.

Results and Discussion

Hydrology in the Instream Flow Segment

According to daily discharge data from the Greys River (USGS gage 13023000) the study period (summer of 2010) occurred during an average water year. The mean daily discharge measured at the Greys River gage during July, August, and September of 2010 (547 cfs) was 11th in magnitude in 20 years of available data.

Mean annual flow was estimated for the Little Greys River instream flow segment in addition to select flood frequency (Table 4) and monthly flow duration estimates (Table 5). Three of the four discharges measured by WGFD in 2010 (Table 6) were lower than the estimated 50% monthly exceedance flows.

TABLE 4. Estimated hydrologic characteristics for the Little Greys River instream flow segment.

Flow Parameter	Estimated Flow (cfs)
Mean Annual	57
1.5-year peak	358
25-year peak	1680

TABLE 5. Estimated monthly exceedance values for the Little Greys River instream flow segment.

Month	50% Exceedance (cfs)	20% Exceedance (cfs)
October	27	34
November	23	28
December	20	24
January	18	22
February	18	21
March	19	23
April	45	81
May	147	216
June	171	247
July	72	122
August	41	55
September	32	40

TABLE 6. Dates of collection and discharge measurements collected in the Little Greys River instream flow segment in 2010.

Date	**Discharge (cfs)**
July 2	87
July 15	47
August 11	28
September 14	24

In addition to monthly exceedance values as an indicator of flow conditions in the segment, daily flow estimates were produced for three representative years (the period of record was first divided to represent wet, average, and dry conditions, and then a representative year randomly selected from each group). Reference gage data from the randomly selected three years were used to prepare daily flow estimates for the Little Greys River segment (Figure 7). These hydrographs indicated the range of discharge conditions that may occur in the instream flow segment; however, in reality there is considerable variation in the timing and pattern of flow within a given year and between different years that is not fully described by three individual hydrographs. As a consequence these should be viewed only as a general template of runoff patterns; flow recommendations from the analyses will not vary as a function of water year characteristics.

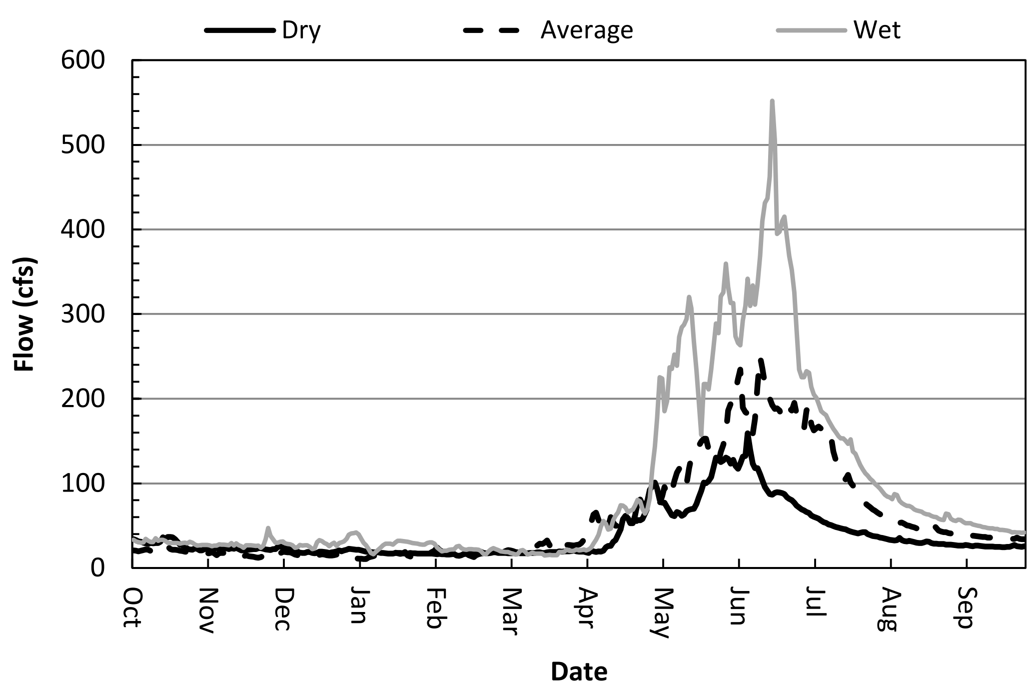

FIGURE 7. Simulated annual hydrographs for randomly selected wet (1971), average (1995), and dry (1981) water years at the Little Greys River instream flow segment.

Biology – Fish Habitat

River2D Model

A River 2D model was created from bathymetry data collected at the field site and calibrated using data collected at three discharges 28 cfs, 47 cfs, and 87 cfs. Calibration was accomplished by adjusting model inputs to closely match field observations of stage (water surface elevation) and velocity. Model inputs included discharge, water surface elevation (at the downstream end of the study site), and a channel roughness factor for each model node (points spaced throughout the study reach where depth and velocity are calculated). To calibrate, the discharge and observed stage were input with the initial roughness values for each node (estimated based on substrate type at each node location), and the predicted water surface elevation was compared to the observed elevation at several points along the study site. To improve predicted elevation values from the model, initial roughness values were adjusted up (to raise predicted water surface elevation) or down (to lower the elevation) in locations where there was error. These adjustments improved the model predictions.

Using the 28 cfs discharge data for calibrating first (more calibration points were collected at that flow), the model was improved such that all water surface elevation points (n=255) were within 8.3 inches of the observed values and 95% of the values were within 3.5 inches (Figure 8). While 8.3 inches is a substantial deviation between observed and predicted water surface elevation in a stream of this size, some of these points are likely observations that occurred in areas of local disturbance that the model does not accurately calculate in sufficiently fine scale. The high proportion of points that were predicted at 3.5 inches (about 20% of the bankfull depth of riffles) or less deviation from observed conditions suggests that the model is a good fit. In addition, there is no systematic error (Figure 8) that would suggest that overall model fit could be improved with adjustments in roughness. With error relatively similar across modeled points throughout the study site, adjustments that improve model predictions in some areas would decrease the prediction accuracy in other areas. There were fewer water surface elevation points taken at the 47 cfs (n=50) and 87 cfs (n=66) discharges due to time constraints in the field, but deviation between simulated and observed elevations were similar to the results observed from the model at 28 cfs discharge. All of the predicted elevation values at 47 cfs were within 2.8 inches of observed values and all predicted elevation values at 87 cfs were within 4.8 inches of observed values. For both the 47 cfs and 87 cfs modeled flows, the simulated elevation of most points were predicted to be very close to the observed elevations and lends further support that the model is a good one.

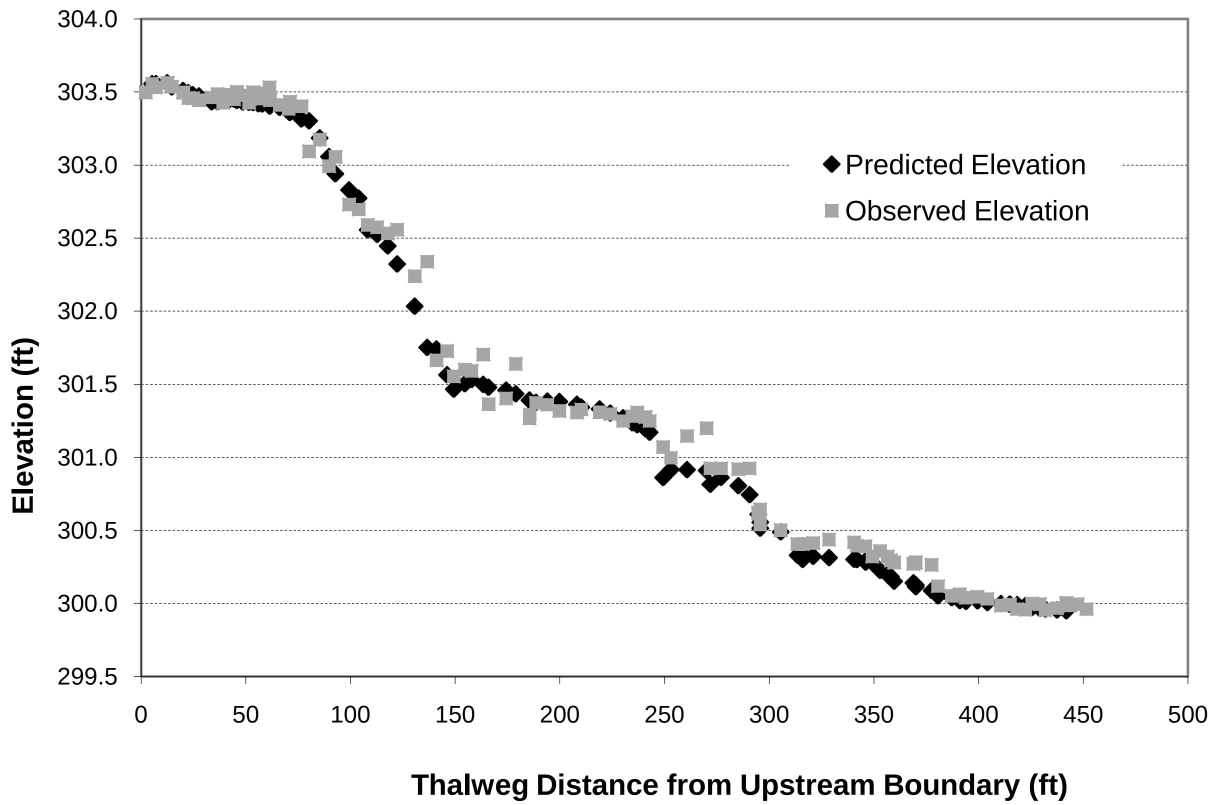

FIGURE 8. Final model-predicted and observed water surface elevations at 28 cfs along the left bank in the Little Greys River study site.

Velocity calibration was accomplished by comparing modeled and observed velocities across two cross-sections in the study reach at three discharges (28 cfs, 47 cfs, and 87 cfs). In each case slight adjustments to roughness were made to improve model fit and the results for water surface elevations. Because data were collected for cross-sections, it was possible to match the pattern of velocity across the channel rather than focus on individual measurements. Figure 9 shows an example of these results at the 87 cfs calibration flow. The final patterns matched closely despite errors in individual measurements of up to 1.0 ft per second. In all cases, the modeled values were similar to the observed pattern of velocity across the channel.

Once the River 2D model was calibrated, simulations were conducted for the study site over a range of flows between 5 cfs and 650 cfs. This range of flow modeling included the predicted 20% exceedance flow for January and February to a little below bankfull flow (914 cfs). Five cfs increments were simulated up to 100 cfs; the increments increased to 10 cfs between 100 and 150 cfs, to 25 cfs between 150 cfs and 250 cfs, and to 50 cfs between 250 cfs and 650 cfs. At each flow, the calibrated River 2D model predicted depth and velocity (and other values such as Froude number and shear velocity magnitude) at all node locations and interpolated values between nodes. These data, combined with the substrate conditions, allowed predictions of available habitat for the species/life stages of interest.

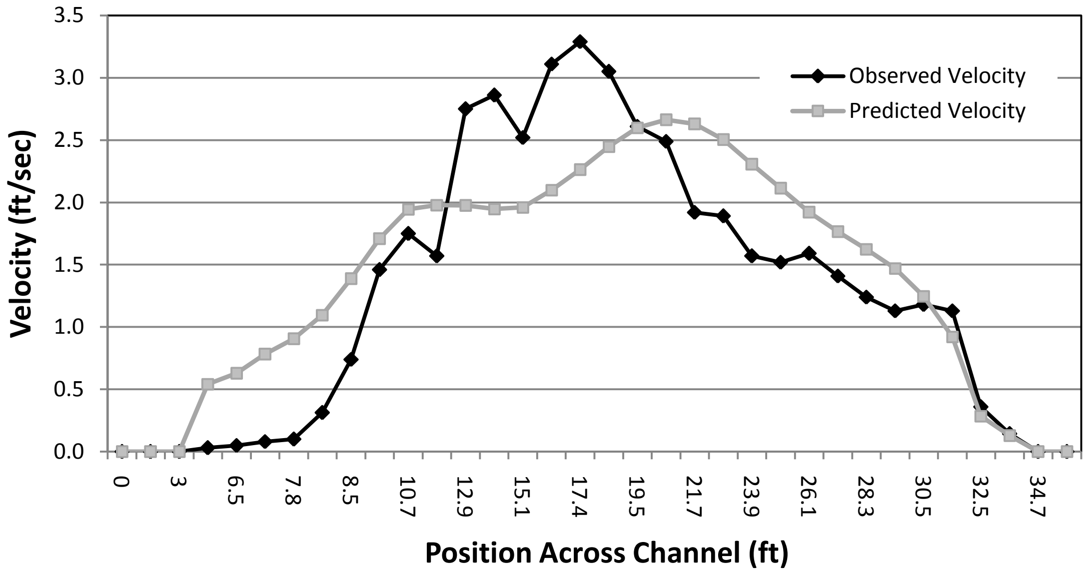

FIGURE 9. Final model-predicted and observed velocities at 87 cfs along the downstream cross-section in the Little Greys River study site.

Habitat suitability curves representing the four life stages (fry, juvenile, adult, and spawning) of SRC were used to interpret the hydraulic conditions predicted at each flow by the River 2D model. Depth, velocity, and substrate data were used to estimate a combined suitability value for each life stage in all areas in the study site. Each area was multiplied by the combined suitability value to generate a weighted usable area (WUA) for the entire study site for a given life stage and discharge.

A review of change in WUA over the range of flows revealed discharge values that provide the amount of physical habitat at each specified flow. For SRC fry, the peak in habitat suitability occurs at the lowest modeled flow, 5 cfs (Figure 10FIGURE). This is because all suitable habitat occurs along the stream margins, backwater habitats, and isolated pools which become less suitable for fry as velocities increase (Figure 11). Overall, there is a moderate amount of fry habitat in this reach, which is likely to harbor fry during the summer. Habitat availability for fry drops considerably at flows of 45 cfs or greater, but some habitat remains at these flows and would exist in other areas of the stream at those flow values. It is common for the PHABSIM model to identify very low flows as having the greatest habitat conditions for fry, but the true range of habitat conditions used by fry (including backwaters, side channels, among large cobbles and boulders) are not thoroughly accounted for in this model. Instream flow recommendations for low flows that appear to favor fry would be damaging to other life stages and benthic invertebrates.

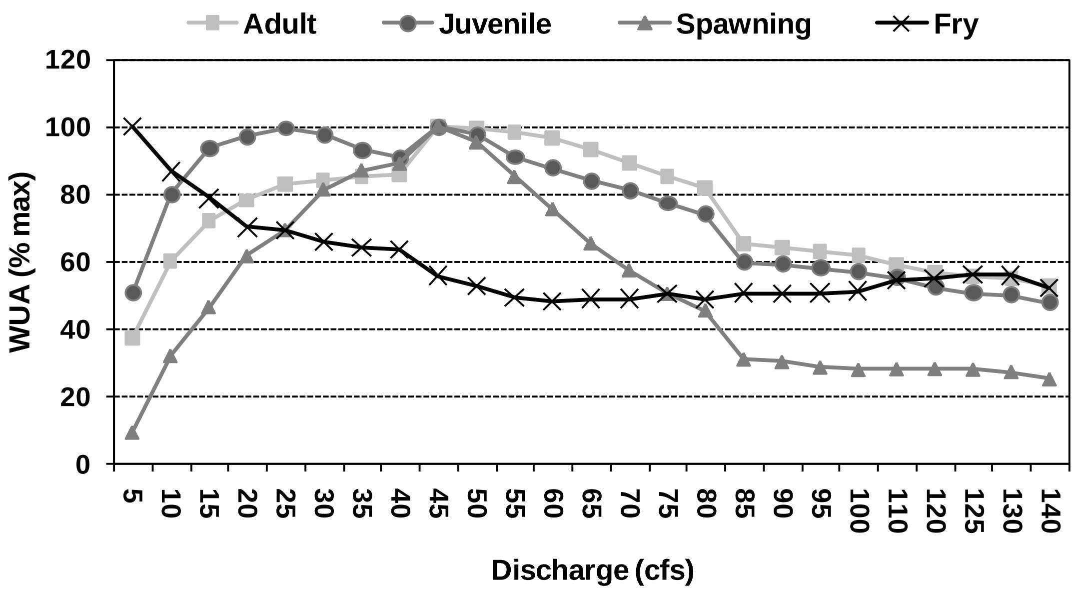

FIGURE 10. Relationship between weighted usable area and discharge for all life stages of SRC in the Little Greys River study site.

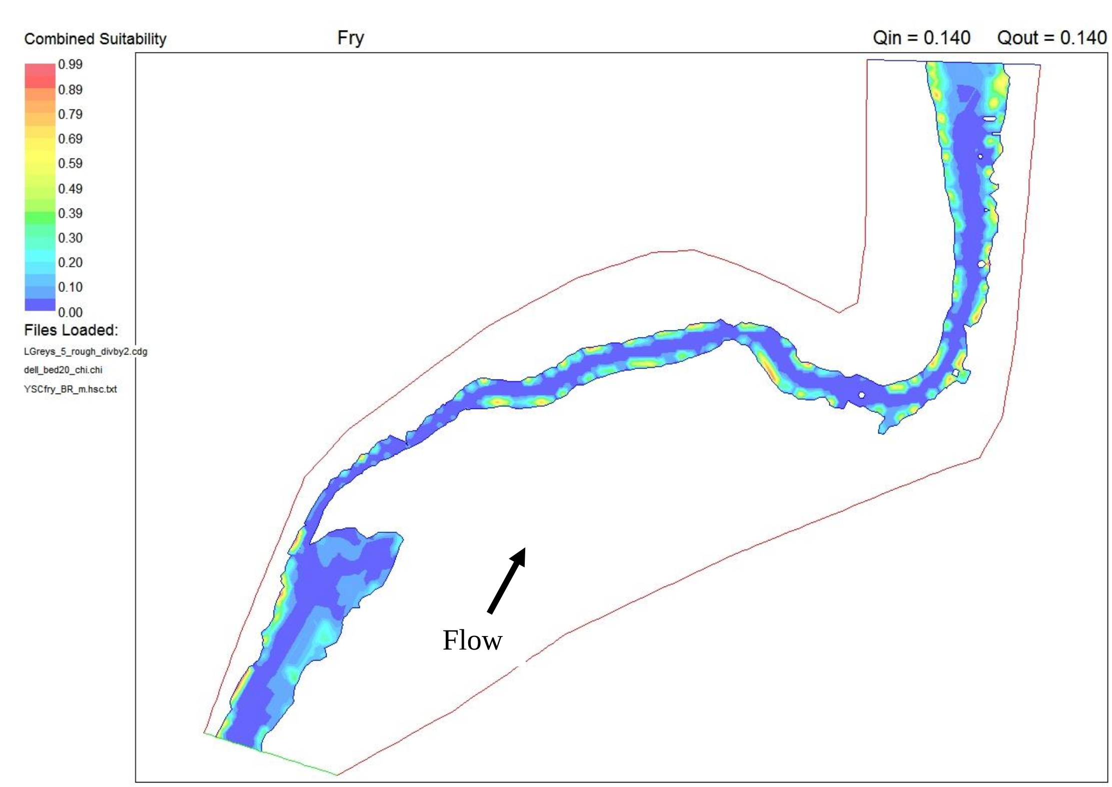

FIGURE 11. Combined suitability for SRC fry in the Little Greys River study site at 5 cfs discharge. Higher values indicate greater suitability of an area to SRC based on its depth, velocity, and substrate characteristics.

For juvenile SRC, habitat suitability is maximized at 45 cfs (Figure 10). Unlike habitat conditions for fry, habitat availability for juvenile SRC is low at 5 cfs, increases with increasing discharge to the peak condition, and then declines with additional discharge. At the peak condition (Figure 12), suitable habitat occurs throughout the reach, generally in pools formed at channel bends and in slower habitats along channel margins. A similar pattern was observed in models at other discharges.

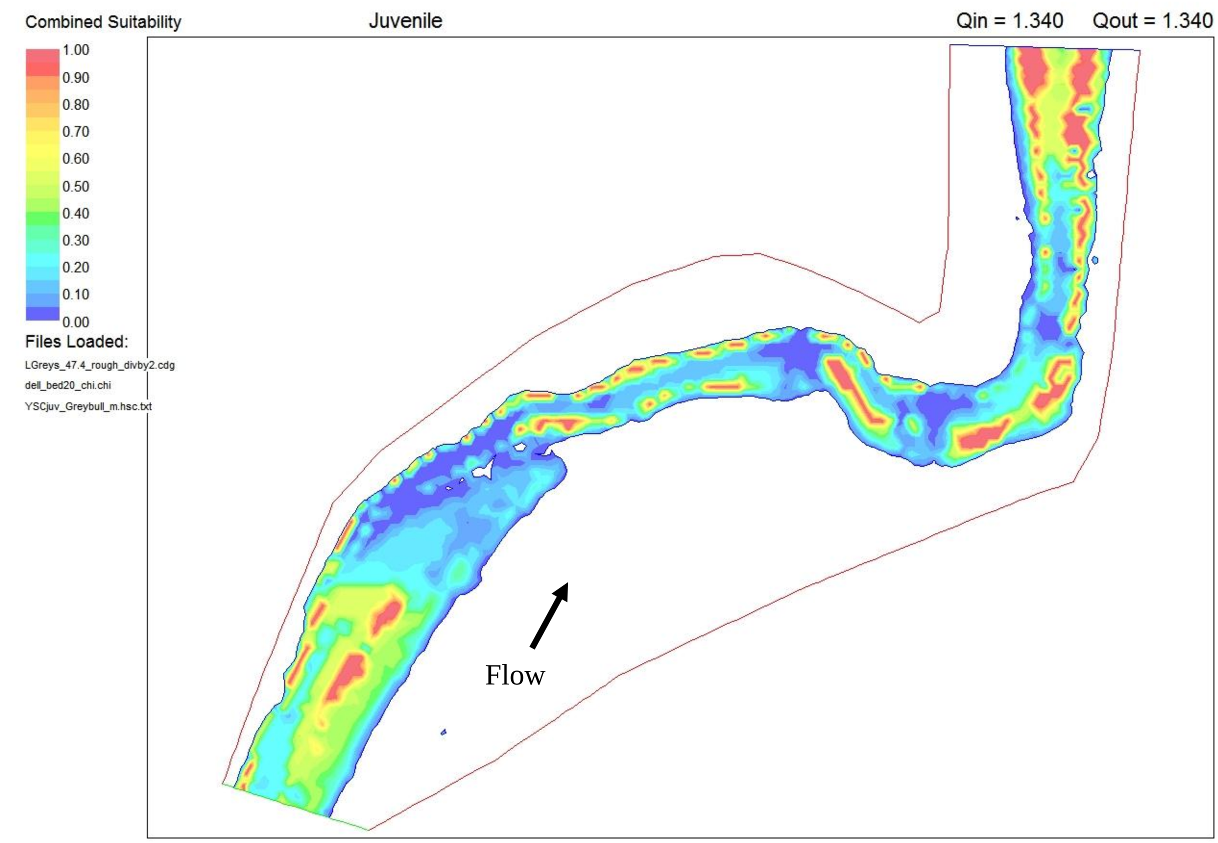

FIGURE 12. Combined suitability for juvenile SRC in the Little Greys River study site at 45 cfs discharge. Higher values indicate greater suitability of an area to SRC based on its depth, velocity, and substrate characteristics.

For adult SRC, habitat availability is maximized at 45 cfs (Figure 10). Similar to habitat conditions for juvenile SRC, habitat suitability for adult SRC increases slowly with discharge to the peak condition and then declines slowly with greater discharge. Suitable habitat for adult SRC (Figure 13) occurs in nearly the same areas as for juvenile SRC when at 45 cfs, but there is more high suitability habitat (0.9 combined suitability or greater) for adult SRC in the reach compared to that for juvenile SRC.

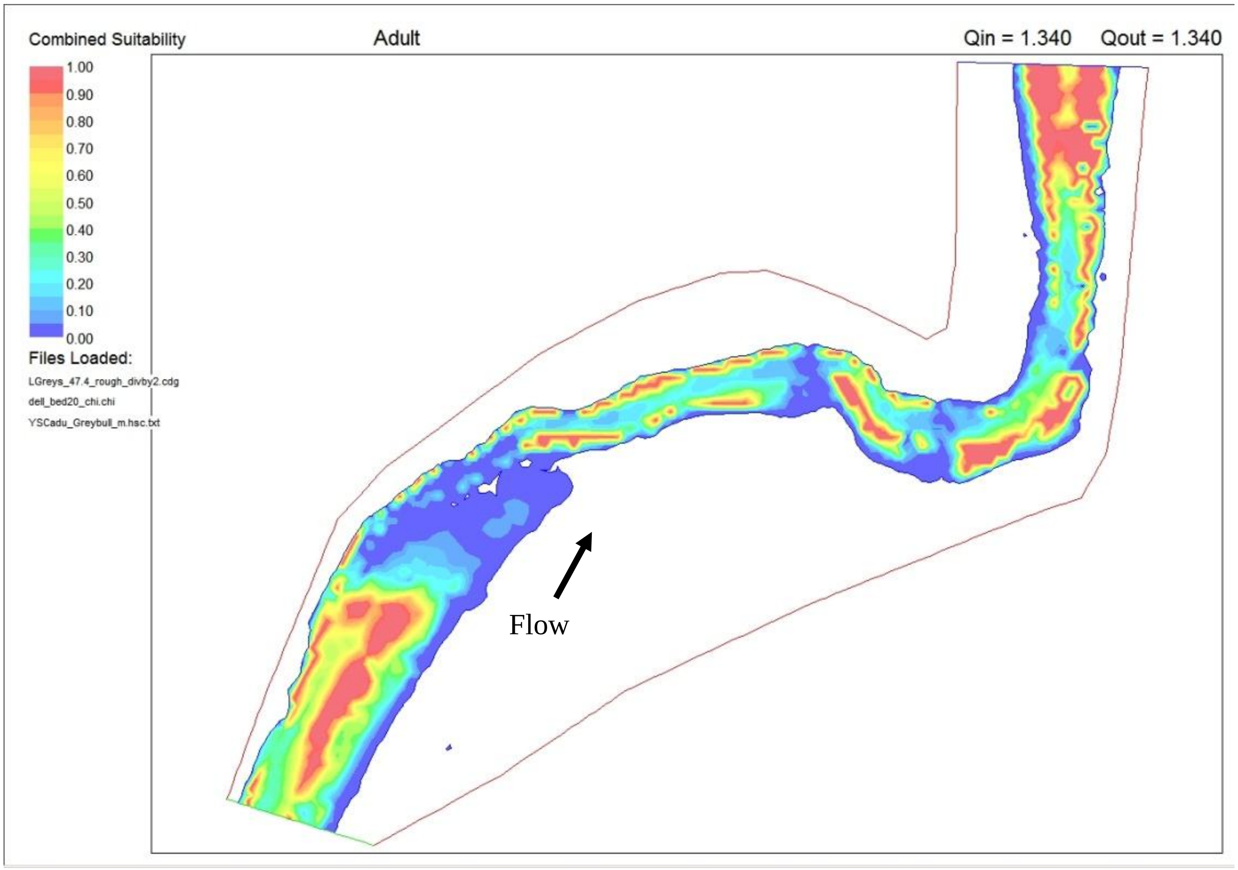

FIGURE 13. Combined suitability for adult SRC in the Little Greys River study site at 45 cfs discharge. Higher values indicate greater suitability of an area to SRC based on its depth, velocity, and substrate characteristics.

For spawning SRC, habitat suitability is also maximized at 45 cfs (Figure 10). Spawning habitat for SRC is common in the study site (Figure 14) and is an important habitat to maintain in this stream. The 50% exceedance flows for May and June (when SRC spawn) were estimated at 422 and 450 cfs, respectively, so discharge of at least 45 cfs would occur frequently during this period. However, the model suggests that flows higher than 45 cfs, which would be expected in most years, provide increasingly smaller areas of suitable spawning habitat as discharge increases. Since the species is successfully spawning in the watershed (the SRC population there is described as "abundant" in the WGFD fishery databases) naturally higher flows are not limiting available spawning habitat. The SRC must either be spawning in smaller tributaries, successfully using the small amount of habitat that the model estimates is available under natural flows, or it is possible that there is more suitable habitat for spawning at higher flows in this reach than estimated by the model. Regardless, the model results suggest that there would be a negative consequence on SRC spawning if discharge is allowed to recede below 45 cfs in this section of stream.

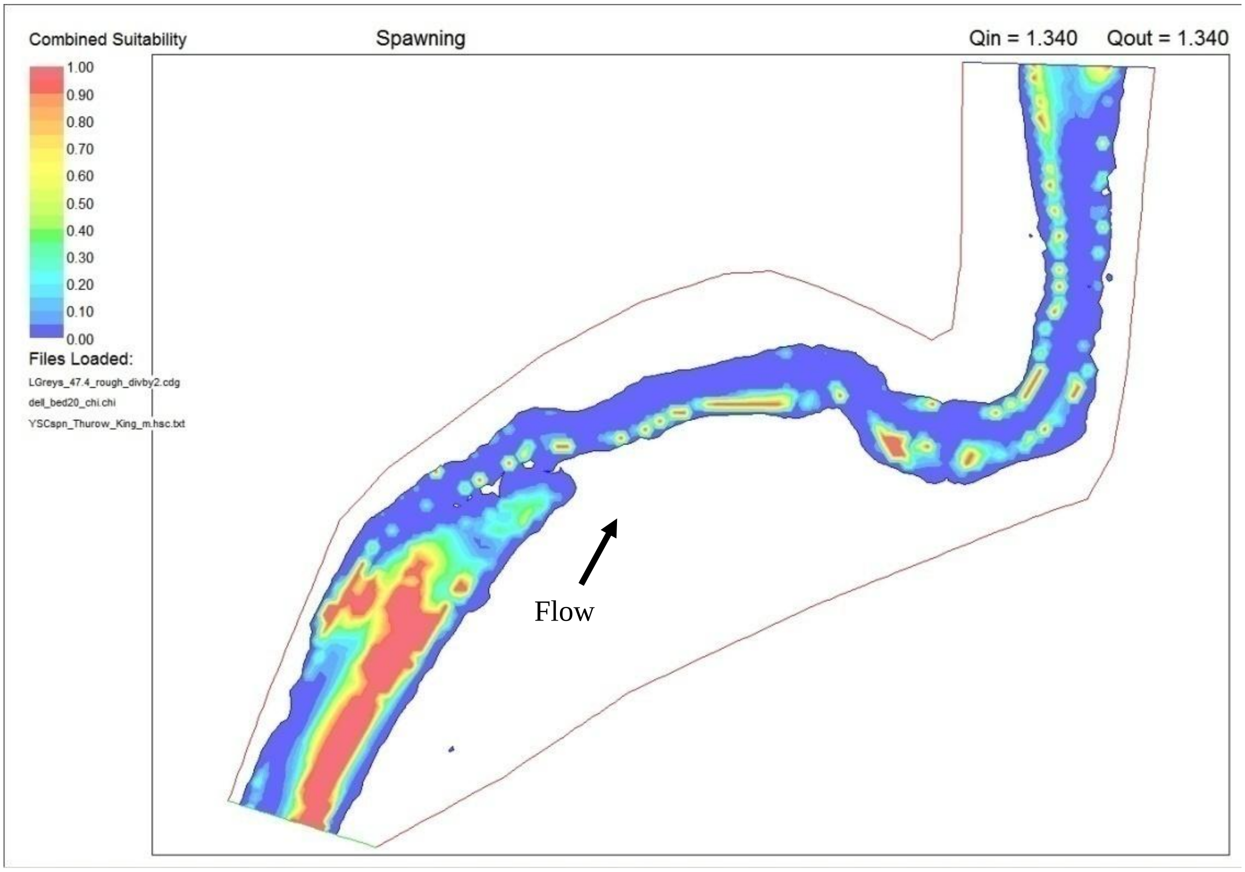

FIGURE 14. Combined suitability for spawning SRC in the Little Greys River study site at 45 cfs discharge. Higher values indicate greater suitability of an area to SRC based on its depth, velocity, and substrate characteristics.

<u>Habitat Retention Model</u>

The habitat retention model was used to evaluate hydraulic characteristics that affect survival and movement of all SRC life stages over a range of discharges in the Little Greys River instream flow segment. This model addresses a portion of the connectivity riverine component as well as the biology riverine component. With this model, the hydraulic characteristics of three riffle transects were estimated and evaluated to determine the discharge that maintains fish passage (connectivity) between habitat types and provides sufficient depth, velocity, and wetted area to ensure survival of fish prey items (benthic invertebrates).

The three hydraulic variables evaluated with this model are mean velocity, mean depth, and the wetted perimeter (as a percentage of bankfull width). The lowest discharge at which two of the three criteria are maintained at all three riffles is the recommended discharge to maintain habitat throughout the instream flow segment (Table 7). Bankfull discharge ranged from approximately 500 cfs to 950 cfs in this reach and at the bankfull flow riffles 1, 2, and 3 resulted in stream widths of 72.7 ft, 43.7 ft, and 61.4 ft.

TABLE 7. Estimated hydraulic conditions at three riffles over the range of modeled discharges in the Little Greys River instream flow segment. Bold indicates that the threshold was met for an individual hydraulic criterion (see Table 2); the greyed-out discharge value meets the selection criteria. Bankfull width (ft) for transect 1 = 72.7, for transect 2 = 43.7, and for transect 3 = 61.4.

Riffle Transect Number	Discharge (cfs)	Mean Velocity (ft/sec)	Mean Depth (ft)	Wetted Perimeter (% of bankfull)
1	950*	11.02	1.19	1.00
	70	2.23	**0.71**	0.61
	40	1.60	0.58	0.60
	18	**1.01**	0.42	0.58
	10	0.73	0.34	0.56
	5.0	0.51	0.25	0.53
	2.0	0.33	0.17	**0.48**
2	500*	7.24	1.580	1.00
	60	2.44	0.68	0.81
	47.4	2.19	0.61	0.79
	23.7	1.63	**0.44**	0.75
	10	1.23	0.27	0.70
	3.5	1.06	0.16	**0.50**
	2.0	**1.04**	0.10	0.42
3	525*	6.50	1.32	1.00
	60	2.64	**0.59**	0.63
	40	2.10	0.50	0.62
	23.7	1.56	0.40	0.61
	10.5	**1.00**	0.30	**0.56**
	5.0	0.85	0.33	0.29
	2.0	0.53	0.25	0.25

*= Bankfull flow

The final result of this analysis indicated that a discharge of 18.0 cfs maintains two of the three hydraulic criteria at all three riffles. This flow would maintain base level conditions for fish passage while providing habitat for benthic invertebrate populations across the riffles.

Habitat Quality Index Model

The HQI model data (Figure 15) were important in evaluating late summer habitat production potential for this instream flow segment. The 50% exceedance flow value for August and 20% exceedance flow value for September were 40 cfs and 41 cfs, respectively (Table 5). At discharges between 31 and 41 cfs, the stream provides 53.2 Habitat Units (Figure 15). The lowest flow that would maintain the amount of habitat equal to that provided by the 50% exceedence flow for August and 20% exceedance flow for September is 31 cfs. Decreasing discharge to 30 cfs or lower would decrease the number of Habitat Units by at least 18%. The final result of this analysis indicates that a discharge of 31 cfs maintains adult SRC habitat during the late summer period.

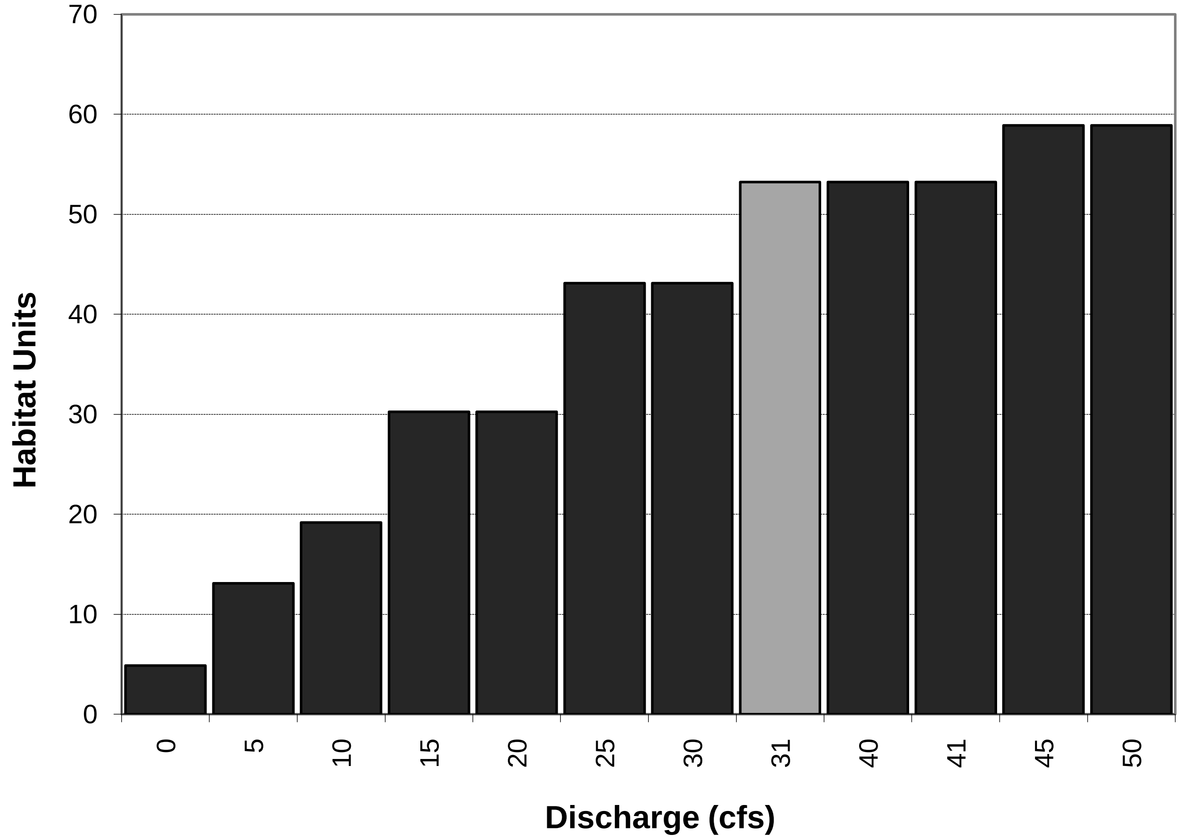

FIGURE 15. Habitat Quality Index Habitat Units vs. discharge in the Little Greys River instream flow segment. X-axis values are not to scale; the values were chosen to indicate where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

Natural Winter Flow

Between October and March, the estimated monthly 20% exceedance values in the proposed instream flow segment ranged from 21 cfs to 34 cfs (Table 5). Compared to the Habitat Retention result (18 cfs recommendation; Table 7), the lowest natural monthly flow of 28 cfs is higher. Since the Habitat Retention flow recommendation may not be fully protective of natural winter habitat conditions, the recommended flow for the winter season is 21 cfs.

Geomorphology

Currently, the Little Greys River watershed has not been dramatically altered by human development. A detailed description of recommended flows for maintenance of channel form in the proposed instream flow segment over the long term is presented in Appendix B. While the habitat modeling efforts presented above resulted in flow recommendations to support fisheries habitat in the existing channel, periodic higher flows ensure that habitat conditions are supported over a longer time frame. The dynamics of channel maintenance and the importance of these flows to fisheries habitat is described in more detail in that section.

Water Quality

Water quality conditions in the Greys River watershed are considered excellent in and upstream of the instream flow segments during most times of year and in most years. There are some issues with turbidity in the watershed, particularly in areas that have unstable slopes, but water temperature, and various organic and inorganic constituents are believed to be at normal (historic) levels and relatively little anthropogenic pollution is apparent.

Flow recommendations in this report are expected to maintain water quality within the natural range of variability. If drastic long-term changes to watershed form or function occur, then flow recommendations should be reviewed relative to water quality conditions, as well as changes to the existing relationship between flow and fish habitat.

Connectivity

Connectivity in a stream includes the ability of fish to move up and downstream, but also includes the connection of the stream to its floodplain and the groundwater. In addition, these connectivity factors have a temporal relationship (e.g., migration of fish and inundation of the floodplain are most important during certain seasons). In the Greys watershed, there are some barriers to migration (i.e., road culverts), but connectivity is largely un-impacted in this watershed. Maintaining needed flows on a continuous basis throughout the year will address the connectivity elements.

Instream Flow Recommendations

The instream flow recommendations to maintain short-term habitat for SRC in the Little Greys River (Table 8; Figure 16) assume that geomorphic characteristics of the stream do not change. Four seasonal time periods were identified for instream flow recommendations. These distinct seasons include winter fish survival (October 1–March 31), an early spring period (April 1–30) that is important for longitudinal habitat connectivity in anticipation of SRC spawning, the spring SRC spawning period (May 1–June 30), and the summer months that facilitate trout production (July 1–September 30).

Winter flow recommendations were based on a combination of Habitat Retention results and the lowest 20% monthly exceedance value during the winter period for each segment. Early spring recommendations were based on adult and juvenile habitat requirements (determined using the River 2D model). Recommendations for the spring spawning period were based on peak SRC spawning habitat suitability determined using the River 2D model. Summer flow recommendations were based on habitat requirements to maintain fry habitat (River 2D results) as well as adult and juvenile trout production (HQI results). In a few cases, habitat models indicated that most favorable conditions were greatest for target species / life stages at discharges that are higher than what naturally occurs in the segment. In those instances a different model result was used, or as a last resort, the 20% exceedance flow (the lowest monthly value estimated for the given time period) was recommended.

The recommendations to maintain seasonal fishery needs for the Little Greys River instream flow segment are:

- Winter (October 1–March 31) – Natural winter flows of up to 21 cfs are needed to maintain over-winter survival of all life stages of SRC at existing levels. This is the lowest estimated value for the 20% monthly exceedance discharge for any month during that time period (the range is 21-34 cfs). Habitat Retention results suggest that this flow would provide sufficient habitat to allow connectivity among habitats in the reach.

- Early Spring (April 1-30) – Natural flow up to 45 cfs is needed based on a combination of River2D results for adults and juvenile SRC and Habitat Retention results. This flow is intended to maintain longitudinal connectivity within the instream flow segment. Connectivity between habitats is particularly important during this time period as SRC move to spawning areas and prepare to spawn.
- Spring (May 1 – June 30) – Natural flow up to 45 cfs is needed based on maximum spawning habitat availability for SRC (River2D results). This level of flow will maintain existing habitat for this life history need and is consistent with observations of spawning activity during field data collection.
- Summer (July 1 – September 30) – Natural flow up to 31 cfs is needed based on HQI results to maintain sufficient habitat conditions for growth and production of juvenile and adult SRC.

TABLE 8. Flow recommendations (cfs) for the proposed instream flow segment in the Little Greys River.

Study Segment	Winter Oct 1 – Mar 31	Early Spring Apr 1 – Apr 30*	Spring May 1 – Jun 30*	Summer Jul 1 – Sep 30
Little Greys River	21	45	45	31

* Channel maintenance flow recommendations for the spring runoff period are higher, and can be found in Appendix B.

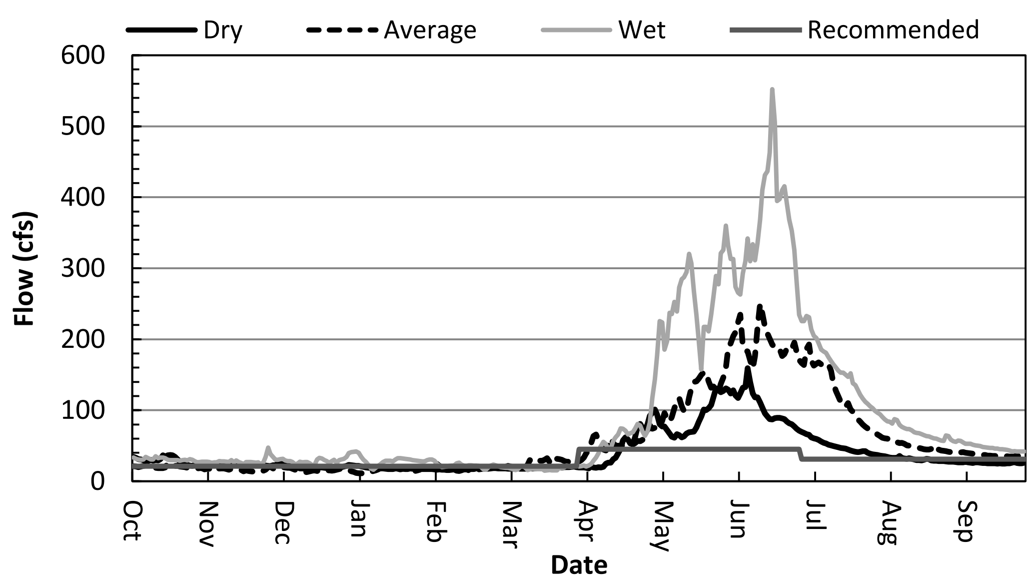

FIGURE 16. Recommended instream flows (when available) in the proposed segment relative to flow conditions observed in representative wet, dry, and average flow years.

Summary

The Little Greys River provides important SRC habitat for ensuring the long-term persistence of the species in the Greys River drainage and throughout Wyoming. This population is managed as a wild SRC fishery within the recreationally important Greys River watershed. If approved by the State Engineer, the proposed instream flow water right filing in the Little Greys River will maintain existing base flow conditions when they are naturally available against presently unknown future out-of-channel uses up to the limit of recommended water rights for each segment described in this report. Approximately 4.5 miles of stream habitat will be directly maintained if these instream flow applications advance to permit status. Existing (senior) water rights will remain unaffected if the proposed water rights are approved because the proposed instream flow rights will have a current day (junior) priority date and water for all senior water rights would be honored in their entirety when water is available according to state law.

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Appendix A. Instream Flows in Wyoming

Guiding Principles for Instream Flow Recommendations

The analyses and interpretation of data collected for this report included consideration of the important components of an aquatic ecosystem and their relationship to stream flow. Stream ecosystems are complex, and maintaining this complexity requires an appropriate flow regime. This report describes recommendations for instream flows that were developed using an ecosystem approach that is consistent with contemporary understanding of stream complexity and effective resource management. The recommendations of the Instream Flow Council (IFC), an organization of state and provincial fishery and wildlife management agencies, provide comprehensive guidance on conducting instream flow studies. The approach described by the IFC includes consideration of three policy components (legal, institutional, and public involvement) and five riverine components (hydrology, geomorphology, biology, water quality and connectivity; Annear et al. 2004). Sections of this report were selected to reflect appropriate components of that template as closely as possible. By using the eight components described by the IFC as a guide, we strive to develop instream flow recommendations that work within Wyoming's legal and institutional environment to maintain or improve important aquatic resources for public benefit while also employing a generally recognized flow quantification protocol.

Legal and Institutional Background

The Wyoming Game and Fish Department (WGFD) manages fish and wildlife resources under Title 23 of Wyoming statutes (W.S.). The WGFD was created and placed under the direction and supervision of the Wyoming Game and Fish Commission (Commission) in W.S. 23-1-401 and the responsibilities of the Commission and the WGFD are defined in W.S. 23-1-103. In these and associated statutes, the WGFD is charged with providing ". . . *an adequate and flexible system for the control, propagation, management, protection and regulation of all Wyoming wildlife*." The WGFD mission statement is: "Conserving Wildlife - Serving People", while the WGFD Fish Division mission statement details a stewardship role toward aquatic resources for the people who enjoy them. In a 2005 policy statement, the Commission formally assigned certain responsibilities for implementing instream flow water rights to the WGFD and specified procedures for notifying the Commission of instream flow filing activities. Briefly, the Department is directed to notify a Commission member when a stream in his or her district is identified as a candidate for filing. If that Commission member has concern about the proposed recommendation, it will be brought to the full Commission in open session. In addition, the Department will advise all Commission members at least two weeks prior to submitting materials for each instream flow filing recommendation, as well as provide notice of any changes in the Instream Flow Program.

The instream flow law, W.S. 41-3-1001-1014, was passed in 1986 and establishes that "*unappropriated water flowing in any stream or drainage in Wyoming may be appropriated for instream flows to maintain or improve existing fisheries and declared a beneficial use..*." The statute directs that the Commission is responsible for determining stream flows that will "*maintain or improve*" important fisheries. The WGFD fulfills this function under the general policy oversight of the Commission. Applications for instream flow water rights are signed and held by the Wyoming Water Development Office on behalf of the state should the water right be approved by the State Engineer. The priority date for the instream flow water right is the day the application is received by the State Engineer.

One of the critical terms associated with the present instream flow statute relates to the concept of a "fishery." From a natural resource perspective, a fishery includes the habitat and associated natural processes that are required to support fish populations. The primary components that comprise needed physical habitat include, but are not limited to, the stream channel, riparian zone and floodplain, as well as the processes of sediment flux and riparian vegetation development that sustain those habitats (Annear et al. 2004). To maintain the existing dynamic character of an entire fishery, instream flow regimes must maintain the stream channel and its functional linkages to the riparian corridor and floodplain to perpetuate habitat structure and ecological function. The State Engineer has concluded that a full range of channel maintenance flow regimes is not consistent with the legislative intent of the instream flow statute. Therefore, until interpretation of state water law changes, channel maintenance flow recommendations are not included on instream flow applications. Channel maintenance flow requirements are presented in Appendix B of this report and may be useful should opportunities arise in the future to secure a broader, more appropriate range of instream flow water rights for this important fishery management purpose.

Through January 2012, the WGFD has forwarded 115 instream flow water right applications to the Wyoming Water Development Office for submission. Of these, the State Engineer has permitted 86 and the Board of Control has adjudicated 10.

Public Participation

The general public has several opportunities to be involved in the process of identifying instream flow segments or commenting on instream flow applications. Individuals or groups can inform WGFD of their interest in protecting the fisheries in specific streams or stream segments with instream flow filings. In addition, planning and selection of future instream flow study sites are detailed in the Water Management Unit's annual work schedules and five-year plans, which are available for public review and comment (either upon request or by visiting the WGFD web site at http://wgfd.wyo.gov). The public is also able to comment on instream flow water rights that have been filed with the State Engineer through public hearings (required by statute) that are conducted by the State Engineer's Office for each proposed instream flow water right. The State Engineer uses these public hearings to gather information for consideration before issuing a decision on the instream flow water right application. To help the public better understand the details of instream flow filings and the public hearing process, WGFD personnel typically conduct an informal information meeting a week or two prior to each public hearing. Additional presentations to community or special interest groups at other times of year also provide opportunity for discussion and learning more about instream flow issues and processes.

Appendix B. Channel Maintenance Flows

Background

The term "channel maintenance flows" refers to flows that maintain existing channel morphology, riparian vegetation and floodplain function (Schmidt and Potyondy 2004). The basis and approach used below for defining channel maintenance flows applies to snowmelt-dominated gravel and cobble-bed (alluvial) streams. By definition, these are streams whose beds are dominated by loose material with median sizes larger than 0.08 in. and with a pavement or armor layer of coarser materials overlaying the channel bed. In these streams, bedload transport processes determine the size and shape of the channel and the character of habitat for aquatic organisms (Andrews 1984, Hill et al. 1991, Leopold 1994).

A flow regime that provides channel maintenance results in stream channels that are in approximate sediment equilibrium, where sediment export equals sediment import on average over a period of years (Leopold 1994, Carling 1995, Schmidt and Potyondy 2004). Thus, stream channel characteristics over space and time are a function of sediment input and flow. When sediment-moving flows are removed or reduced over a period of years, some gravel-bed channels respond with reductions in width and depth, rate of lateral migration, stream-bed elevation, stream side vegetation, water-carrying capacity, and changes in bed material composition.

Maintenance of channel features and floodplain function cannot be obtained by a single threshold flow (Kuhnle et al. 1999). Rather, a dynamic hydrograph within and between years is needed (Gordon 1995, Trush and McBain 2000, Schmidt and Potyondy 2004). High flows are needed in some years to scour the stream channel, prevent encroachment of stream banks, and deposit sediments to maintain a dynamic alternate bar morphology and a riparian community with diverse successional states. Low flow years are as valuable as high flow years on some streams to allow establishment of riparian plant seedlings on bars deposited in immediately preceding wet years (Trush and McBain 2000). The natural interaction of high and low flow years maintains riparian plant community development and aquatic habitat by preventing annual scour that might occur from continuous high flow (allowing some riparian development) while at the same time preventing encroachment by riparian plants that could occur if flows were artificially reduced at all times.

Channel maintenance flows must be sufficient to move the entire volume and all sizes of material supplied to the channel from the watershed over a long-term period (Carling 1995, Schmidt and Potyondy 2004). A range of flows, under the dynamic hydrograph paradigm, provides this function. Infrequent high flows move large bed elements while the majority of the total volume of material is moved by more frequent, but lower flows (Wolman and Miller 1960, Leopold 1994). In streams with a wide range of sediment sizes on the channel boundary, a range of flows may best represent the dominant discharge because different water velocities are needed to mobilize different sizes of bed load and sediment. Kuhnle et al. (1999) noted "A system designed with one steady flow to transport the supplied mass of sediment would in all likelihood become unstable as the channel aggraded and could no longer convey the sediment and water supplied to it. A system designed with one steady flow to transport the supplied sediment size distribution would in all likelihood become unstable as the bed degraded and caused instability of the banks."

Bedload Transport

A bedload transport model (Figure B-1) shows the total amount of bedload sediment transported over time (during which a full range of stream discharge [Q] values occur). Smaller discharges, such as the substrate mobilization flow (Q_m) occur more frequently, but not much sediment is moved during those times. The effective discharge (Q_e) mobilizes the greatest volume of sediment and also begins to transport some of the larger sediment particles (gravels and small cobbles). The bankfull discharge (Q_{bf}), in which flow begins to inundate the floodplain and which has a return interval of approximately 1.5 years on average, typically occurs near the Q_e. The discharge corresponding to the 25-year return interval (Q_{25}) represents the upper limit of the required channel maintenance flow regime, since the full range of mobile sediment materials move at flows up to this value, but these higher flows are infrequent. The more frequent discharges that occur between the Q_m and the Q_e move primarily smaller-sized particles (sand and small gravel) and prevent filling in of pools and other reduction in habitat complexity. Since these particles are deposited into the stream from the surrounding watershed with greater frequency, it is important to maintain a flow regime that provides sufficient conveyance properties (high frequency of moderate discharges) to move these particles through the system. However, alluvial streams, particularly those at higher elevations, also receive significant contributions of larger-sized particles from the surrounding watershed and restrictions to the flow regime that prevent or reduce the occurrence flows greater than Q_e (which are critical for moving these coarser materials) would result in gradual bedload accumulation of these larger particles. The net effect would be an alteration of existing channel forming processes and habitat (Bohn and King 2001). For this reason, flows up to the Q_{25} flow are required to maintain existing channel form and critical habitat features for local fish populations.

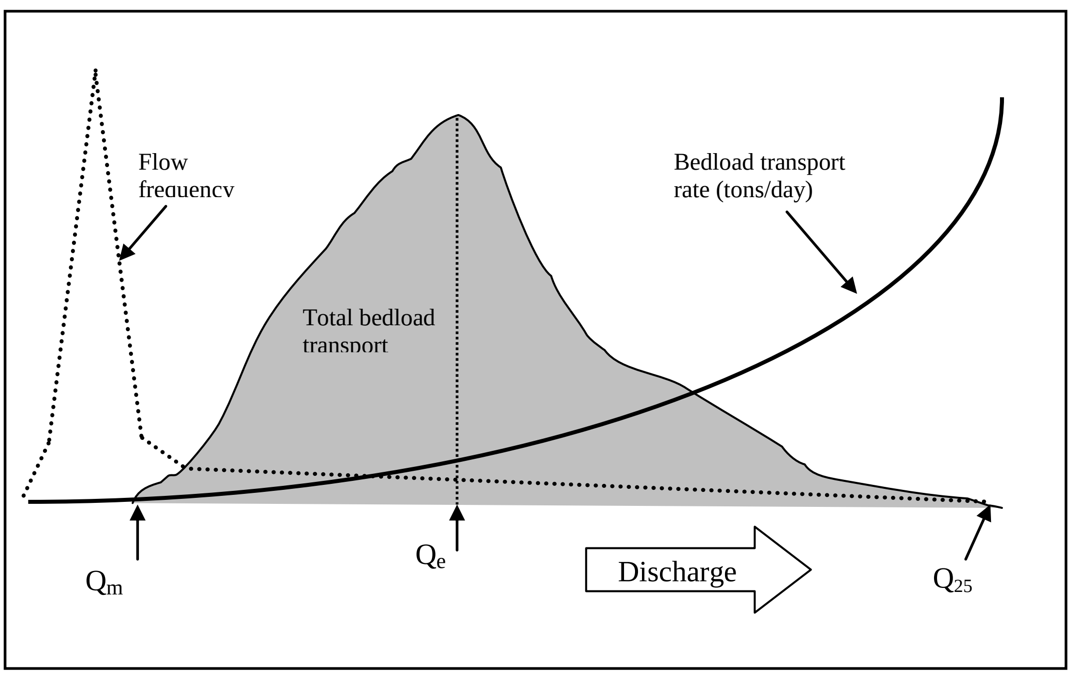

FIGURE B-1. Total bedload transport as a function of bedload transport rate and flow frequency (adapted from Schmidt and Potyondy 2004).

Channel Maintenance Flows Model

The model used to recommend flows to maintain the form and function of the stream channel is derived from bedload transport theory presented above. Based on these principles, the following channel maintenance flow model was developed by Dr. Luna Leopold and is used in this report to calculate the appropriate instream flows up to the Q_{25}:

$$Q\ \text{Recommendation} = Q_f + \{(Q_s - Q_f) * [(Q_s - Q_m) / (Q_{bf} - Q_m)]^{0.1}\}$$

Where:

Q_f = fish flow (required to maintain fish habitat)
Q_s = actual stream flow
Q_m= sediment mobilization flow = 0.8 * Q_{bf}
Q_{bf} = bankfull flow

The Leopold model calculations could be used to yield a continuous range of instream flow recommendations at flows between the Q_m and Q_{bf} for each cubic foot per second increase in discharge. However, this manner of flow regulation is complex and could prove burdensome to water managers. To facilitate flow administration while still ensuring reasonable flows for channel maintenance, WGFD modified this aspect of the approach to recommend instream flows for four quartiles between the Q_m and Q_{bf}.

Channel maintenance flow recommendations developed with the Leopold model require that only a portion of the flow remain instream for maintenance efforts. When total discharge is less than Q_m, only fish flows are necessary; discharge between the fish habitat flows recommended in the main body of this report and Q_m is available for other uses (Figure B-2). Similarly, all discharge greater than the Q_{25} flow is less critical for channel maintenance purposes and available for other uses (these higher flows do allow a connection to the floodplain and it is valuable for infrequent inundation of riparian habitat to occur, but not for the physical maintenance of the stream channel). Between the Q_m and Q_{bf}, the model is used to determine what proportion of flow should remain in channel for maintenance activities. For those relatively infrequent flows that occur in the range between Q_{bf} and the Q_{25}, all flow is recommended to remain in the channel for these critical channel maintenance purposes.

Using this “dynamic hydrograph” approach, the volume of water required for channel maintenance is variable from year to year. During low-flow years, less water is recommended for channel maintenance because flows may not reach the defined channel maintenance level. In those years, most water in excess of fish habitat flows is available for other uses. The majority of flow for channel maintenance occurs during wet years. One benefit of this dynamic hydrograph approach is that the recommended flow is needed only when it is available in the channel and does not assert a claim for water that is not there as often happens with a threshold approach.

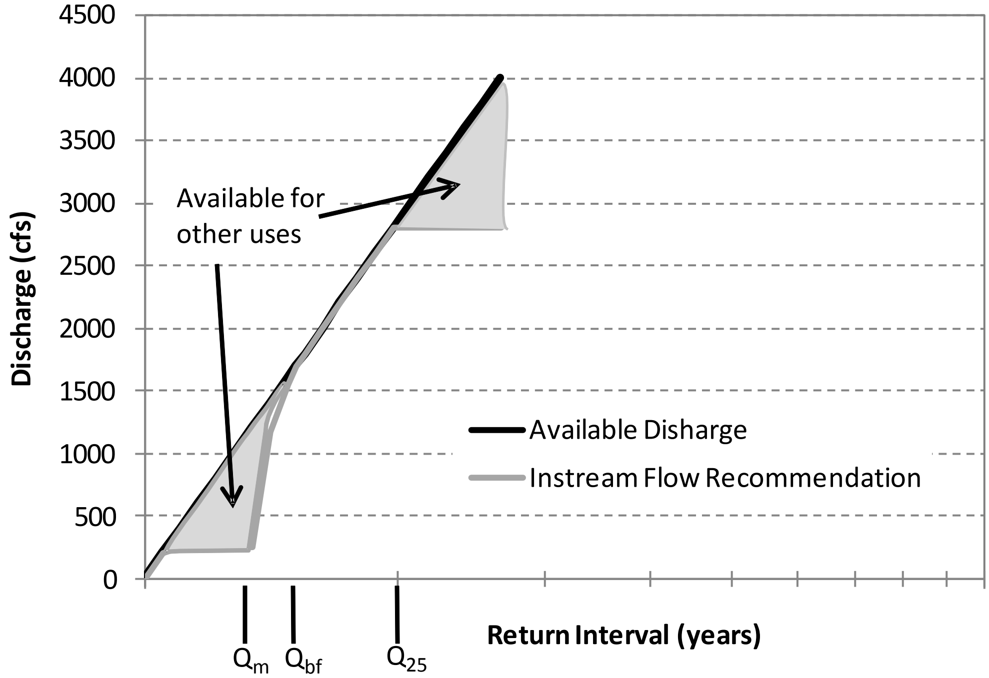

FIGURE B-2. General function of a dynamic hydrograph instream flow for fishery maintenance. Q_m is substrate mobilization flow, Q_{bf} is bankfull flow, and Q_{25} is the discharge with a 25-year return interval.

This channel maintenance flow model is the same as the one presented in Gordon (1995) and the Clark's Fork Wild and Scenic water right (C112.0F) filed by the U.S. Forest Service with the Wyoming State Engineer, with one exception. The model presented in those documents used the average annual flow to represent Q_m. More recent work by Schmidt and Potyondy (2004) identified Q_m as occurring at a discharge of 0.8 times Q_{bf}. Initial particle transport begins at flows somewhat greater than average annual flows but lower than Q_{bf} (Schmidt and Potyondy 2004). Ryan (1996) and Emmett (1975) found the flows that generally initiated transport were between 0.3 and 0.5 of Q_{bf}. Movement of coarser particles begins at flows of about 0.5 to 0.8 of Q_{bf} (Leopold 1994, Carling 1995). Schmidt and Potyondy (2004) discuss phases of bedload movement and suggest that a flow trigger of 0.8 of the Q_{bf} "provides a good first approximation for general application" in defining flows needed to maintain channels.

Little Greys River

Like all properly functioning rivers, the Little Greys River has a hydraulically connected watershed, floodplain, riparian zone, and stream channel. Bankfull and overbank flow are essential hydrologic characteristics for maintaining habitat in and along these river segments in their existing dynamic form. These high flows flush sediments from the gravels and maintain channel form (i.e., depth, width, and pool and riffle configuration) by periodically scouring encroaching vegetation. Overbank flow maintains recruitment of riparian vegetation, encourages lateral movement of the channel, and recharges ground water tables. Instream flows that maintain the connectivity of these processes over time and space are needed to maintain the existing fishery (Annear et al. 2004).

The Leopold model was used to develop channel maintenance recommendations for the Little Greys River instream flow segment (Table B-1). The fish flow used in the analysis was the spawning flow (45 cfs). For naturally available flow levels less than the spawning flow, the channel maintenance instream flow recommendation is equal to natural flow. The spawning flow level is substantially less than Q_m (45 cfs). For the flow range between the spawning flow and Q_m, the channel maintenance flow recommendation is equal to the spawning flow (Table B-1). When naturally available flows range from Q_m to Q_{bf}, the Leopold formula is applied and results in incrementally greater amounts of water applied toward instream flow (Table B-1). At flows between Q_{bf}, and Q_{25}, all stream flow is retained in the channel to perform maintenance functions. At flows greater than Q_{25}, only the Q_{25} is recommended for channel maintenance (Figure B-1).

TABLE B-1. Channel maintenance instream flow recommendations (May 1–June 30) to maintain existing channel forming processes and long-term aquatic habitat characteristics in the Little Greys River instream flow segment.

Flow Description	Available Flow (cfs)	Recommended Flow (cfs)
<Spawning Flow	<45	All available flow
Spawning Flow to Q_m	45-731	45
Q_m to Q_{bf} – Quartile 1	732-777	453
Q_m to Q_{bf} – Quartile 2	778-823	684
Q_m to Q_{bf} – Quartile 3	824-868	772
Q_m to Q_{bf} – Quartile 4	869-914	847
Q_{bf} to Q_{25}	915-4605	All available flow
> Q_{25}	≥ 4605	4605

Figure B-3 shows example annual hydrographs (randomly selected average and wet years) with channel maintenance flow recommendations implemented. Dry years are not shown because flows would not exceed the 731 cfs substrate mobilization threshold to initiate channel maintenance flows. In the representative average year, 1989, flow exceeded substrate mobilization flow on 11 days, which would trigger channel maintenance flow recommendations. In the representative wet year, 1986, these recommendations would apply for 30 days in May and June (Figure B-3).

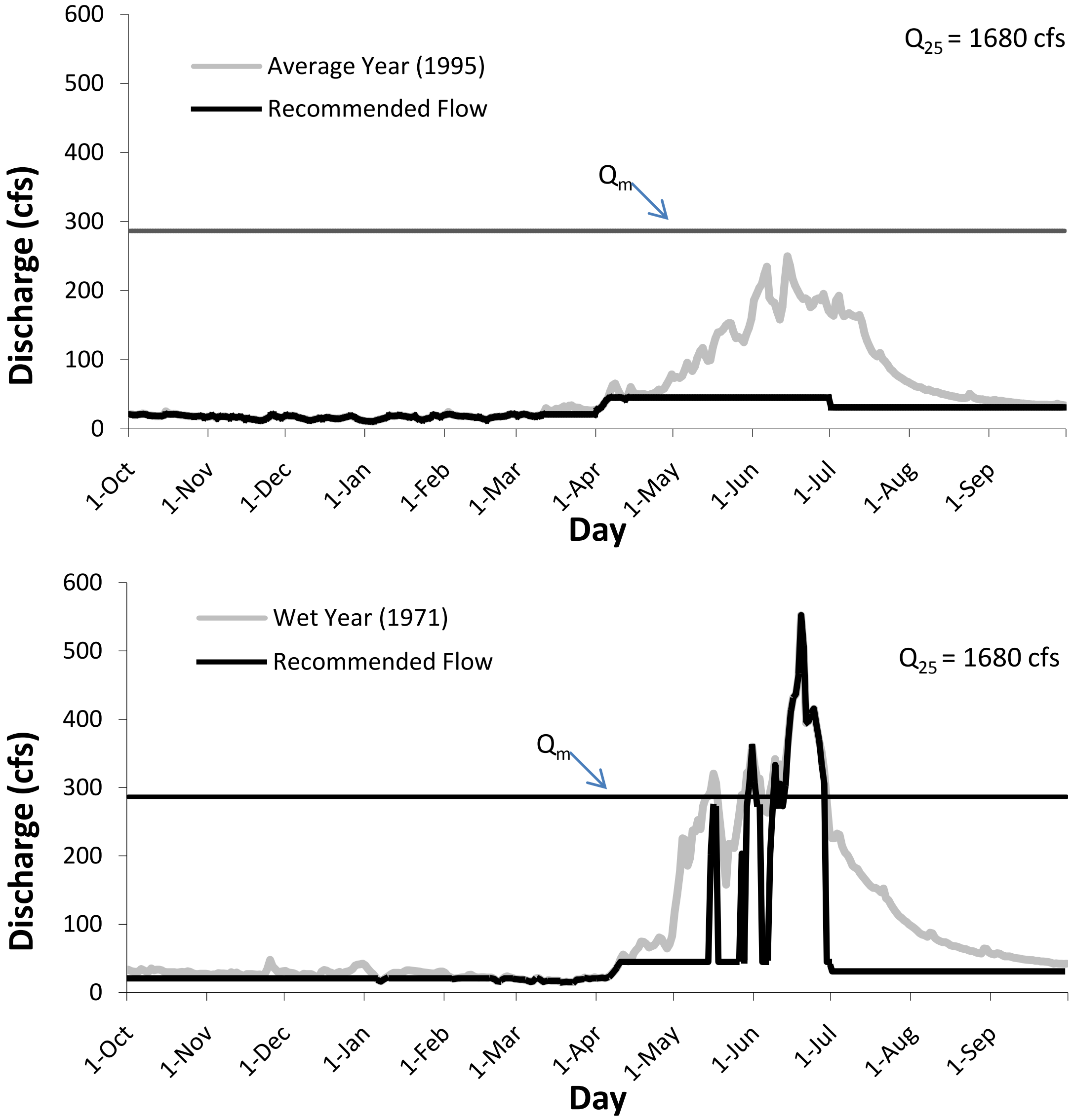

FIGURE B-3. Channel maintenance flow recommendations and hydrographs for the Little Greys River instream flow segment in an average (1995) and a wet (1971) water year. Qm is sediment mobilization flow and Q25 is the discharge corresponding to the 25-year return interval.

Implementing these flow recommendations would have to include moderating the abrupt changes that occur at threshold flows with a ramping scheme that includes more gradual changes akin to a natural hydrograph. Such sharp flow increases and decreases evident in Figure B-3 would cause habitat loss through excessive scour and potential trout mortality due to stranding. The Index of Hydrologic Alteration (IHA; Richter et al. 1996) could provide a valuable reference to find suitable rates of change. Daily increases and decreases during runoff measured at the Greys River gage (USGS gage 13023000) could serve as a guide for developing such ramping rate recommendations using the IHA.